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Astronomical Observatory,
Adam Mickiewicz University,
Poznań, Poland.

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1. Chaos, Resonances & Stability 2. Kuiper Belt Objects 3. Satellites, Minor Planets, Comets, and Meteors 4. Orbit Uncertainty and Error Analysis for NEO and Artificial Satellites 5. Stellar and Galactic Dynamics 6. Drag and Atmospheric Modeling & Theory (Non-gravitational Force Modeling) 7. Numerical Methods, Parallel Processing, Ephemeris Generation 8. Satellite Constellation Dynamics and Control 9. Orbit and Attitude Dynamics 10. NEO and Debris Observations and Motions 11. Reference Systems for Astronomy and Astrodynamics 12. Exo-planetary systems 13. General perturbations methods

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- Iwona Wytrzyszczak.

Abstracts are listed in alphabetical order. All contributions are labeled as in following example:

- OP.II.3 – an oral presentation number 3 during the session II
- PP.13 – a poster number 13

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- Kompania Piwowarska S.A, Poznań, Poland

PROGRAM

Monday July 3

8:00 – 10:00 – **Registration**

10:00 – 10:40 – **Opening**

10:40 – 11:00 – Coffee Break

Session I: Rigid Bodies Dynamics

11:00 – 11:30 – Antonio Elipe (invited)
OP.I.1: On the Attitude Dynamics of Perturbed Triaxial Rigid Bodies

11:30 – 12:00 – Christopher D. Hall (invited)
OP.I.2: Attitude Dynamics of Orbiting Gyrostats

12:00 – 12:20 – Yu. V. Barkin
OP.I.3: Progress of the Perturbation Theory of the Attitude Dynamics

12:20 – 12:40 – Jason Wm. Mitchell, David L. Richardson
OP.I.4: A Simplified Kinetic Element Formulation for the Rotation of a Perturbed Mass Asymmetric Rigid Body

12:40 – 13:00 – Andrzej J. Maciejewski
OP.I.5: Rigid Bodies Problems in Celestial Mechanics

13:00 - 15:00 – Lunch

Session II: Two and Three Body Problems

15:00 – 15:20 – Martin W. Lo
OP.II.2: Chaotic Celestial Pachinko

15:20 – 15:50 – Shane D. Ross (invited)
OP.II.1: Resonance and Capture of Jupiter Comets

15:50 – 16:10 – A.I.Neishtadt, C.Simo, V.V.Sidorenko
OP.II.3: Stability of Planar Satellite Motions in a Circular Orbit

16:10 – 16:30 – D.J. Scheeres
OP.II.4: Coupling of Translational and Rotational Motion Through Mutual Gravitation of Two Bodies

16:30 – 17:00 – Coffee Break

17:00 – 17:20 – S. Ferrer, F. Mondejar and A. Vigueras
OP.II.5: Symmetries, Reductions and Relative Equilibria for a Gyrostat in the Three-Body Problem

17:20 – 17:40 – Luis Floria
OP.II.6: Solving a Gylden-Mescerskij System in Delaunay-Scheifele-Like Variables

17:40 – 18:30 – Discussion: Resonances and Chaos
(Chairperson: A.Morbidelli)

19:30 - 21:00 – Cocktail (Hotel "Polonez")

Tuesday July 4

Session III: Artificial Satellite Dynamics I

9:00 – 9:30 – Kyle T. Alfriend, Deok-Jin Lee (invited)
OP.III.1: Covariance Propagation for Earth Satellites

9:30 – 9:50 – Alexei Golikov
OP.III.2: THEONA, New Version: An Efficient Tool for Orbit Dynamics

9:50 – 10:10 – Boris Bardin, Andrzej Maciejewski
OP.III.3: Quasi-static Motions of Viscoelastic Satellites in the Gravitational Field. Problems of Stability and Nonlinear Oscillations

10:10 – 10:30 – S.P.Rudenko, V.K.Tarady, A.V.Sergeev, N.V.Karpov
OP.III.4: Determination of Orbit of Geosynchronous Space Debris Kupon Satellite Using its CCD Observations at 2-meter Telescope at Terskol Peak

10:30 – 11:00 – Coffee Break

Session IV: Artificial Satellite Dynamics II

11:00 – 11:30 – A.I.Nazarenko, V. Yurasov, P. Cefola, R. Proulx, G. Granholm (invited)
OP.IV.1: Monitoring of Variations of the Upper Atmosphere Density

11:30 – 11:50 – Krystyna Kurzyńska, Alina Gabryszewska
OP.IV.2: Influence of the Local Troposphere on GPS Measurements

11:50 – 12:10 – Andrzej Bobojć, Andrzej Drożyner
OP.IV.3: Orbit Determination Using Satellite Gravity Gradiometry

12:10 – 12:30 – A.I.Nazarenko, V. Yurasov
OP.IV.4: Semi-analytical Models of Satellites Motion for Russian Space Surveillance System

12:30 – 12:50 – Paulo H. C. N. Lima Jr., Sandro da Silva Fernandes, Rodolpho V. de Moraes
OP.IV.5: Semi-Analytical Method to Study Geopotential Perturbations Considering High Eccentric Resonant Orbits

12:50 – 15:00 – Lunch

Session V: Satellite Constellations

15:00 – 15:30 – Giovanni B. Palmerini (invited)
OP.V.1: Coordinated Orbital Control for Satellite Constellations and Formations

15:30 – 15:50 – Andrei Baranov
OP.V.2: Optimal Rendezvous in Near-Circular Orbits

15:50 – 16:10 – Kyle T. Alfriend, Dong-Woo Gim, Hanspeter Schaub, Srinivas R. Vadalim
OP.V.3: Formation Flying Satellites: Control by an Astrodynamicist

16:10 – 16:30 – Andrei Baranov, Alexei Golikov
OP.V.4: Optimal Maneuver Schedule for Constellation Keeping and Formation

16:30 – 17:00 –Coffee Break

17:00 – 17:30 – Wang S. Koon (invited)
OP.V.5: Dynamical Systems, Three-Body Problem and Space Mission Design

17:30 – 18:30 – Discussion: Artificial Satellite Orbits
(Chairperson: Kyle T. Alfriend)

19:30 - 22:30 - Garden party in the Observatory Park (US National Holiday)

Wednesday July 5

Session VI: Resonances

9:00 – 9:30 – David Nesvorny (invited)
OP.VI.1: A New Vision of the Mean Motion Resonances in the Solar System

9:30 – 9:50 – L.E. Bykova, T.Yu. Galushina
OP.VI.2: Near-Earth Asteroids Close to Mean Motion Resonances: The Orbital Evolution

9:50 – 10:10 – Sylvie Jancart, Anne Lemaitre
OP.VI.3: Second Fundamental Model of Resonance with Asymetric Equilibra

10:10 – 10:40 – Sławomir Breiter (invited)
OP.VI.4: Lunisolar Resonances Revisited

10:40 – 11:10 – Coffee Break

Session VII: Dynamics of asteroids

11:10 – 11:30 – Smiliana Dikova, Tomyo Petrosky
OP.VII.1: An Alternative Theory of Asteroid Dynamics (Size and Lifetimes of Asteroidal Resonances - Application of Complex Spectral Analysis)

10:10 – 10:30 – Sergei A. Klioner
OP.VII.2: Multi-dimensional Fourier Transformation of Planetary Disturbing Function

11:30 – 11:50 – A.A.Vakhidov
OP.VII.4: Influence of Joint Perturbations from Jupiter and Saturn on the Chaotical Behaviour of Orbits of Minor Planets

11:50 – 12:10 – Fabrice Thomas
OP.VII.5: Analytical and Numerical Study of Long-Term Dynamics for Trojan-Type Asteroids

12:10 – 12:30 – Grzegorz Michalak
OP.VII.6: Determination of Masses of Six Asteroids from Close Asteroid-Asteroid Encounters

12:30 – 12:50 – Olga Vasilkova
OP.VII.7: Schwarzschield's Nonequatorial Periodic Motion About an Asteroid Modeled as a Triaxial Rotating Ellipsoid

13:10 – 15:00 – Lunch

Session VIII: Dynamics of Near Earth Asteroids

15:00 – 15:30 – Alessandro Morbidelli (invited)
OP.VIII.1: Origin, Evolution and Unbiased Distribution of Near Earth Asteroids

15:30 – 15:50 – Stefan Berinde
OP.VIII.2: A Quantitative Approach of the Orbital Uncertainty Propagation Through Close Encounters

15:50 – 16:10 – Morano Fernandez J.A., Lopez Garcia A., Pastor Erade J.
OP.VIII.3: Predictions, Observation and Analysis of Asteroid's Close Encounters

16:10 – 16:30 – Rosaev A.E.
OP.VIII.4: The Reconstruction of Genetic Relations Between Minor Planets, Based on their Orbital Characteristics

16:30 – 17:00 – Coffee Break

17:00 – 17:30 – Karri Muinonen, Jenni Virtanen, Edward Bowell (invited)
OP.VIII.4: Collision Probability for Earth-Crossing Asteroids

17:10 – 18:10 – Discussion: Near Earth Objects
(Chairperson: Karri Muinonen)

Thursday July 6

Session IX: Comets and Meteors

9:00 – 9:30 – Iwan P. Williams (invited)
OP.IX.1: Meteor Stream Dynamics

9:30 – 10:00 – Giovanni B. Valsecchi, Claude Froeschle, Tadeusz J. Jopek (invited)
OP.IX.2: Meteor Stream Identification with Geocentric Variables

10:00 – 10:20 – Ji-Lin Zhou, Yi-Sui Sun
OP.IX.3: On the Transfer of Comets from Near-parabolic to Short-period Orbits

10:20 – 10:40 – Piotr A. Dybczynski, Halina Pretka-Ziomek
OP.IX.4: Dynamically New Comets in the Solar System

10:40 – 11:10 – Coffee Break

Session X: Dynamics of Natural Satellites of Planets

11:10 – 11:30 – M.A. Vashkovyak
OP.X.1: Evolution of the Orbits of Distant Satellites of Uranus

11:30 – 11:50 – J.-E. Arlot, W. Thuillot, Ch. Ruatti
OP.X.2: Mutual Events of the Saturnian Satellites: A Test of the Dynamical Models

11:50 – 12:10 – V.Lainey, A.Vienne And L.Duriez
OP.X.3: Small Perturbations on the Galilean Satellites

12:10 – 12:30 – Abdel-Naby Saad, Hiroshi Kinoshita
OP.X.4: An Analytical Theory of Motion of Nereid

12:30 – 12:50 – Patrick Bidart
OP.X.5: A New Solution for Moon's Planetary Perturbations

12:50 – 13:10 – Luis Benet
OP.X.6: Planetary Rings with Shepherds: Generic Aspects

13:10 – 15:00 – Lunch

Session XI: Resonances and Stability

15:00 – 15:30 – Claude Froeschle, Massimiliano Guzzo, Elena Lega (invited)
OP.XI.1: Analysis of the Validity of the Fast Lapunov Indicator to Study the Structure of Symplectic Mappings. Application to the Transition from Nekhoroshev Regime to the Chirikov One

15:30 – 15:50 – V. Lanchares, T. Lopez Moratalla
OP.XI.2: Lyapunov Stability for Lagrange Equilibria of Orbiting Dust

15:50 – 16:10 – Philippe Robutel, Jacques Laskar
OP.XI.4: Frequency Map and Global Dynamics in the Solar System : Short Period Dynamics of Massless Particles

16:10 – 16:40 – Coffee Break

16:40 – 17:40 – Discussion: Small Solar System Bodies
(Chairperson: I. Williams)

19:00 – 21:00 – Closing Dinner (Hotel "Polonez")

Friday July 7

Session XII: Non-gravitational effects and observations

9:00 – 9:30 – D. Vokrouhlicky, A. Milani and S.R. Chesley (invited)
OP.XII.1: Could the NEA Dynamics Reveal Existence of the Yarkovsky Effect?

9:30 – 9:50 – M. Broz, D. Vokrouhlicky
OP.XII.2: The Peculiar Orbit of Vysheslavia: Further Hints for its Yarkovsky Driven Origin?

9:50 – 10:10 – Bykova L.E., Parfenov E.V.
OP.XII.3: Near-Earth Asteroids Orbits Improvement Using Singular Values

10:10 – 10:30 – Eleonora I. Yagudina
OP.XII.4: The Usage of Radar and Optical Observations of Near-Earth Asteroids and Main Belt Minor Planets for Astrometry (Orbit Determination, Parameters Orientations, Mass Determinations)

10:30 – 11:00 – Coffee Break

Session XIII: Kuiper Belt Objects: Dynamics and Observations

11:00 – 11:30 – H. Levison (invited)
OP.XIII.1: Dynamics of the Kuiper Belt

11:30 – 11:50 – J. Klacka, S. Gajdos
OP.XIII.2: Kuiper-Belt Objects: Distribution of Orbital Elements and Observational Selection Effects

11:50 – 12:10 – O. P. Bykov
OP.XIII.3: Short arc CCD observations of celestial bodies: new approach

12:10 – 12:30 – S. M. Kopejkin, N. V. Shuygina, M. V. Vasilyev, E. I. Yagudina, L. I. Yagudin
OP.XIII.4: Modeling of Space Astrometric Observations on the Microsecond Level

12:30 – 15:00 – Lunch

Session XIV: Stellar and Galactic Dynamics

15:00 – 15:30 – Juan C. Muzzio (invited)
OP.IX.1: Stellar Motions in Galactic Satellites

15:30 – 15:50 – J.A. Lopez, M.J. Martinez, F.J. Marco
OP.IX.2: Dynamical Method for the Analysis of the Systematic Errors in Stellar Catalogs

15:50 – 16:10 – Andrzej J. Maciejewski, Maciej Konacki
OP.IX.3: Planetary System Around Pulsar PSR 1257+12 - An Overview

16:10 – 16:40 – Evgeny Griv, Michael Gedalin, David Eichler and Chi Yuan (invited)
OP.IX.4: Resonant Excitation of Spiral Density Waves in Galactic Disks

16:40 – 17:10 – Coffee Break

17:10 – 18:30 – Discussion: Workshop Summary
(Chairperson: P. K. Seidelmann)

POSTER SESSION

Posters area will be available from Monday afternoon to Friday morning.

PP.1: V. Agapov, A. Golikov
Maintaining the Gestationary Objects Catalogue using Relational Database and THEONA Software

PP.2: V.A. Avdyushev, T.V. Bordovitsyna
Algorithms of the Numerical Simulation of the Motion of Large Planets' Satellites

PP.3: A. Tsvetkov, M. Babadjaniants
Constructing of the Stellar Velocity Field Using Hipparcos Data

PP.4: A. Baranov, A. Golikov
Optimal Maneuver Schedule for Constellation Keeping and Positioning

PP.5: Yu. V. Barkin
Dynamics of the Planet Shells: New Problems of the Celestial Mechanics and Applications

PP.6: P. Bartczak, S. Breiter
The Improved Model of Potential for Irregular Bodies

PP.7: Jagdish Singh, Bhola Ishwar
Nonlinear Stability in Generalised Photogravitational Restricted Three Body Problem

PP.8: T. Borkovits
Tidal and Rotational Effects in the Long-Time Evolution of Hierarchical Triple Stellar Systems

PP.9: M. Buciora, S. Breiter
The Method of Close Returns in the Restricted Kokoriev-Kirpichnikov Problem

PP.10: O. P. Bykov, V. N. L'vov
Astrometric Accuracy of the Kuiper Belt Asteroids CCD Observations

PP.11: V. S. Filonenko
Determination of Precise Optical Positions of Some Compact Extragalactic Radio Sources from CCD Observations

PP.12: P. N. Fedorov, F. P. Velichko
The First Results of Astrometrical CCD Observations of Extragalactic Reference Sources at Kharkov Observatory

PP.13: S. Gajdos
NEO Observation Program at Astronomical Observatory in Modra

PP.14: K. Gozdziewski
Nonlinear Stability of Lagrangean Equilibria in a Problem of a Rigid Body and a Point Mass

PP.15: N. Petrova, A. Gusev
Modern Problems of the Physical Libration of the Moon

PP.16: A. Gusev, N. Petrova
Observational Effects of the Lunar Core-Mantle Differential Rotation

PP.17: P. Kankiewicz
Moon-Earth Separation Problem in the Dynamics of Near Earth Asteroids

PP.18: I. Yu. Kiryushkin, M.Yu. Ovchinnikov
MUNIN Attitude Determination by Image Processing Algorithm

PP.19: J. Klacka
On the Poynting-Robertson Effect and Analytical Solutions

PP.20: J. Klacka
Solar Wind and Motion of Meteoroids

PP.21: J. Klacka, S. Gajdos
Meteor Orbits - Selection Criteria. I. Example of a Broad Meteor Stream Analysis

PP.22: J. Klacka, S. Gajdos
Meteor Orbits - Selection Criteria. II. Example of a Narrow Meteor Stream Analysis

PP.23: J. Klacka, M. Gajdosik
Orbital Motion in Outer Solar System

PP.24: J. Klacka, M. Kocifaj
On the Stability of the Zodiacal Cloud

PP.25: J. Klacka, M. Kocifaj
Interaction of Stationary Nonspherical Interplanetary Dust Particle with Solar Electromagnetic Radiation

PP.26: O. M. Kochetova
Determination of Mass of Jupiter and that of Some Minor Planets from Observations of Minor Planets Moving in 2:1 Commensurability with Jupiter

PP.27: N. O. Komarova
Ephemeris Meaning of Parameters of Asteroid's Apparent Motion

PP.28: A. Brunini, F. Lopez-Garcia
Primordial Sculpting of the Region of Semimajor Axes Smaller than 2 AU

PP.29: F.J. Marco, M.J. Martinez, J. A. Lopez
Analysis of Catalog Corrections with Respect to the Hipparcos Reference Frame

PP.30: A. I. Nazarenko, N. N. Smirnov, A. B. Kiselev
LEO Technogeneous Contaminants Evolution Modeling Taking Into Account Satellite's Collisions

PP.31: L. Neslusan
The Photographically Pbserved Meteors of Stream Associated with Comet 18P/Perrine-Mrkos

PP.32: V.V. Pashkevich
Development of the Numerical Theory of the Rigid Earth Rotation

PP.33: A. E. Rosaev
On the Behaviour of Stationar Point in Quasi-Central Configuration Dynamics

PP.34: Z. Sandor, M. H. Morais
A Mapping Model for the Coorbital Problem

PP.35: W. Schulz, A.F.B.A. Prado, R. Vilhena de Moraes
Inclination Change Using Atmospheric Drag

PP.36: I.V. Semenov, V.P. Korobeinikov
On Modeling of Small Celestial Body Fracture in Planet Atmospheres

PP.37: V. P. Stulov
Destruction and Ablation of Meteoroids in Atmosphere of Planets

PP.38: F. Teger
On the Stability of Saturnian Trojans at High Inclinations

PP.39: E. Yu. Titarenko, V. A. Avdyushev, T. V. Bordovitsyna
Numerical Simulation of the Motion of Martian Satellites

PP.40: V. P. Titarenko, L. E. Bykova, T. V. Bordovitsyna
Numerical Simulation of the Motion of Small Bodies of the Solar System by the Symbolic Computation System "Mathematica"

PP.41: A. A. Vakhidov
An Efficient Algorithm for Approximate Evaluation of Hansen Coefficients

PP.42: M. H. Youssef

Relativistic Effects on Sun-synchronous Orbits Including the Influence of Direct Solar Radiation Pressure

PP.43: Ireneusz Włodarczyk:

The Prediction of the Motion of Atens, Apollos and Amors Over Long Intervals of Time

PP.44: I. Wytrzyszczak, S. Breiter

Long Term Evolution of Disposal Orbits Beyond the Geostationary Ring

PP.45: H. Umehara

Self-similar Structure Induced by Linear Three-Body System

PP.46: H. Umehara

An Optical Scanning Search for GEO Debris

PP.47: H. Umehara

Co-location of Geostationary Satellites by Imaginary Interaction

PP.1: Maintaining the Geostationary Objects Catalogue Using Relational Database and THEONA Software

V. Agapov, A. Golikov

Keldysh Institute of Applied Mathematics RAN, Ballistic Center

Increased attention for last decade on studying of near-Earth artifical space objects is caused by whole number of practical tasks, especially, providing of safety of spaceflights. Due to this some issues of space control are appeared. However, information needed for detailed analysis in some situations is presented as rule in different forms and in different sources. Special information model was elaborated during 1994-98 for purposes of collecting, formalization, storing, generalization and analysis various information concerning of space activity, and also for providing some space control and space analysis tasks with such information. This model permits to describe any artifical space object and it's evolution in the course of time in common terms of 'object' and 'event'. It is foreseen that there is a possibility of adding other characteristics of 'objects' and 'events' in case of need. The model was applied for creating of the relational database named 'CATALOGUE OF SPACE OBJECTS'.

At present, each space objects and space event may be described by around of 180 parameters in total. Special database structure permits to store information for the same parameter of a particular object from different sources. It is possible, that this information is contradictory or have different accuracy. In these cases it is possible describe degree of contradictory and store all source references on each particular value. At present, the database contains information about launches (including orbital, suborbital, failed and planned), known space objects resulting from these launches (independently of current their existence or tracking status) and so on. Also, following 'events' are described: docking, fragmentation, manoeuvres, decay and so on. Formal description of object and event types permits to extend possible ones without changing of the database structure. The "CATALOGUE OF SPACE OBJECTS" has a lot of applications. One of them is support of analysts and operators with processing of tracking and other information for geostationary objects. Currently there are more than 800 objects in near-geostationary region. The "CATALOGUE" include not only procedures for filling tables with various data but for analysis and effective automatic processing. Main tasks are: - processing of tracking measurements with THEONA software; - identification of newly observed objects; - maintaining of processed orbital data archive for whole time of each near-geostationary object existence; - maintaining archive of predicted orbital data for quick analysis of current measurements; - planning of observations of objects; - maintaining archive of IERS data; - using general data on space object from the "CATALOGUE" (launch data, geometry of object, stabilization and external satellite constructions data, possible locations for satellite of given type etc.) during analysis; - visualization of evolution of orbital elements, observation conditions etc.; - preparation of various type reports.

OP.III.1: Covariance Propagation for Earth Satellites

Kyle T. Alfriend, **Deok-Jin Lee**

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Many users of the ephemerides provided by US Space Command want an estimate of the accuracy of the orbit prediction using the ephemerides. This accuracy estimate is typically provided by the covariance. The accuracy of the covariance is affected by sensor error modeling, dynamic error modeling and the method propagation of the covariance. Numerical integration of the covariance with the full dynamic force model is the most accurate, but the most computationally expensive. An accurate analytical propagation would save considerable computation time, particularly when one is primarily interested in just determining the estimated error. In this paper we will address the propagation of the covariance and the effect of neglecting the nonlinear effects in the propagation. Two cases will be considered: a) a low Earth orbit satellite with the standard radar observations, and b) a near geosynchronous satellite with optical observations. A comparison of three propagation methods will be performed: a) Numerical integration of the Lyapunov equation in ECI coordinates, b) Analytical propagation in a rotating reference frame fixed to the nominal satellite position (Hill's equations) with a recently developed state transition matrix for elliptic orbits and mean $J2$ effects. A recently developed nonlinearity index for measuring the effect of neglected nonlinearities will be used.

OP.V.3: Formation Flying Satellites: Control by an Astrodynamicist

Kyle T. Alfriend[1], Dong-Woo Gim[2], Hanspeter Schaub[3], Srinivas R. Vadalim[4]

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Satellites flying in formation is a concept being pursued by the Air Force and NASA. One of the purposes is to have many satellites in precise formation replace one large, expensive satellite. An example is that many satellites operating cooperatively could emulate a large antenna. Reliability and survivability of the system would increase because failure of a few satellites would just result in gradual degradation of the performance of the system. N addition, development time and hopefully, cost, would be reduced. In order to achieve this the system needs to operate autonomously.

Potential periodic formation orbits have been identified using Hill's (or Clohessy Wiltshire) equations. Unfortunately the gravitational perturbations destroy the periodicity of the orbits and control will be required to maintain the desired orbits. Since fuel will be one of the major factors limiting the system lifetime it is imperative that fuel consumption be minimized. The gravitational perturbations effect each satellite differently, consequently the fuel requirement to negate the gravitational perturbations will be different for each satellite. To maximize lifetime we not only need to find those orbits which require minimum fuel we also need for each satellite to have equal fuel consumption and this average amount needs to be minimized. Thus, control of the system has to be addressed, not just control of each satellite.

The one advantage we have in this problem is that the physics are well known and the there is considerable knowledge on how optimal maneuvers for satellites, e.g., the Hohmann transfer. Control of the system will be approached not as a standard LQG problem but from an astrodynamics perspective utilizing all the knowledge we have in celestial mechanics (orbit theory) and optimal satellite maneuvers. This approach leads to some interesting new results.

OP.X.2: Mutual Events of the Saturnian Satellites: a Test of the Dynamical Models

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In 1995-1996 mutual events of the Saturnian satellites occurred. These events lead to high accurate astrometric measurements and allow dynamicians to constrain the models of the motions of these satellites. During this period we organized an international campaign to get observations of these events. After collecting the data, performing the reduction of various photometric records, we are able to provide some final results: thanks to the analysis of almost sixty observations, we have computed longitude corrections issued from a comparison to the theoretical Dourneau's model and from the Vienne and Duriez model (TASS) showing the present accuracy of these models.

PP.2: Algorithms of the Numerical Simulation of the Motion of Large Planet Satellites.

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A brief summary of results obtained by the authors on the process of development and application of algorithms of the numerical simulation of the motion of natural and artificial satellites of large planets and the Earth is presented. The using of the algorithms based on Kustaanheimo-Stiefel (KS) equations is substantiated.

It is shown by theoretical and practical outcomes that stabilizing effect of the KS-transformation may be considerable if investigating objects move near its central body having powerful zonal gravitational field. In particular speed of calculation of the space positions of inner satellites of planets increases in four times.

Principles of constructing Encke-type differential equations in KS-variables based on Keplerian intermediate solution are expounded. Results of application of these Encke-type equations in problems of numerical simulation of long-term orbital evolution of some satellites are considered. Results of numerical experiment points at the essential advantage of the Encke-type equations in comparison with another ones. The using of equations in variations of KS-variables improves accuracy of numerical integration almost by one order for the Earth's artificial satellites and by two order for the natural satellites.

New intermediate solution of differential equations of the perturbing motion of near equatorial satellite has been constructed in KS-space. The solution has been written in form of harmonic oscillator which frequency is calculated taking into account the influence of the second zonal harmonics of gravitational field of the central planet. Encke-type algorithms constructed on the basis of the new solution had been approved in problems of dynamics of set of natural satellites. Analysis of the results of numerical experiments shows that the using of new intermediate orbit for forecasting of the motion allows to improve accuracy of numerical integration almost by two order.

OP.XI.3: Short Time Lyapounov Indicators in the Case of a Sun-Jupiter-Saturn-Asteroid System with a Special Care for the Neighbourhood of the 2:1 and 3:2 Resonances

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In our previous papers (Sándor ae al., Rom. Astron. J., 1999; Sándor et al., Cel. Mech. and Dyn. Astron., 2000) we have discussed the application of the short time indicators in the planar circular Restricted Three Body Problem (RTBP) and in the Elliptic Restricted Three-Body problem (ERTBP) in order to distinguish between chaotic and regular domains of the phase space in these problems. The method of stretching numbers was introduced by Voglis and Contopoulos (1994). This method allows a quick distinction between ordered and chaotic regions in Hamiltonian systems of 2 or 3 degrees of freedom, or in 2D and 4D symplectic mappings. Comparing our results with the corresponding Poincaré's surface of section shows this method to be useful for a quick separation between regular and chaotic domains of the phase space. We showed that this method of short-time indicators is very efficient and it needs only 20 iterations per orbit. We also applied the method of stretching numbers to the elliptic restricted three-body problem. As an extension of our investigation, we applied the method of stretching numbers to a realistic Sun-Jupiter-Saturn-Asteroid (SJSA) problem. We represented the structure of the phase-space in the $a-e$ plane, where a is the semimajor axis and e is the eccentricity. For an individual $< s >_N$ curve, where $< s >_N$ is the average value of stretching numbers, the values of the semimajor axis have been taken from the interval $[3.2, 5.2]$ (AU) for a fixed value of the eccentricity of the test particle between $e = 0$ and $e = 0.4$. For a good visualization of the regular and chaotic regions in the $a-e$ plane we have processed the curves of average values calculating the absolute value of their "derivative" $|\frac{\Delta<s>_N}{\Delta a}|$, where $\Delta a = a_{i+1} - a_i$ is the difference between two consecutive initial semimajor axis and $\Delta < s >_N$ is the corresponding change of the average value of stretching numbers. If this derivative is larger than a certain value (in our ! case 0.002), the corresponding region between two neighbouring initial conditions is classified as chaotic. Of course, this method is very empirical, and not necessarily gives reliable results. Its usefulness is based on the very fast and effective way how it approximates the location and size of the regular and chaotic regions. We have found that the structure of the phase-space is very similar in the RTBP and in the ERTB but there is a significant difference in the case of the SJSA. It seems that with the method of stretching numbers we can have a quick distinction between ordered and chaotic domains in the case of the SJSA too. Using this method I also analysed the structure of the $a-e$ plane in the neighbourhood of the $2:1$ and $3:2$ resonances.

The numerical calculations were done by the computer system of the Department of Astronomy, Eötvös University granted partially by the Physics Program of the PhD School of the Eötvös University. The grant OTKA F030147 of the National Research Foundation are also acknowledged. The research was partially sponsored by Ericsson Hungary Ltd..

OP.V.2: Optimal Rendezvous in Near-Circular Orbits

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The present paper states comprehensive numerical-analytical theory of optimal rendezvous in near-circular orbits. The theory has been created for many years, its basic components being of wide use in Keldysh Institute of Applied Mathematics, Russian Academy of Science for the flight control execution of piloted and automatic spacecraft launches. In developing the theory all most typical practical tasks were considered:

1. Optimal free time transfers between coplanar and non-coplanar orbits.

2. Rendezvous in coplanar orbits (3 variants of optimal solutions).

3. Optimal rendezvous of spacecraft that initially were placed into non-coplanar orbits.

4. Rendezvous with the limitation on the altitude of drift orbit.

5. Choosing of the maneuvering scheme (number of impulses etc.) that admits of reducing influence of thruster performance errors and errors of initial determination of orbital elements on the total fuel consumption.

6. Choosing of the maneuvering scheme (revolution numbers for chaser and target spacecraft, etc) allowing optimal rendezvous with considerable initial difference of ascending nodes of the orbits.

Simple numerical-analytical algorithms used to solve all these tasks provide instant solution which is represented graphically. The specified accuracy of building-up the scheduled orbit with regard to all disturbing factors (e.g. non-spherical gravitational field, atmosphere, shut-down impulse etc.) is ensured by the application of the iterative procedure which may use both numerical and numerical-analytical integration. There is also graphical interaction with the task to comply with some additional limitations. Advantages of proposed methods are well shown in solving of the rendezvous problem considered by the NASA group in their work on the Mars 2002/2005 Sample Return Mission.

PP.4: Optimal Maneuver Schedule for Constellation Keeping and Positioning

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The problem of optimal station keeping and positioning for constellation is considered. We propose the method of maneuvre schedule calculation for maintaining of mutual disposition of satellites during long time with needed accuracy. The method utilize the iterative procedure allowing to apply simple algorithms to define impulse parameters and ensuring high accuracy in forming the desired orbits. It is possible to calculate maneuvre schedules for both absolute and relative station keeping.

In the first case the motion of each satellite is associated with the stated one. In the second case the motion of constellation is associated with the reference orbit. The elements of the reference orbit are chosen so that to minimize the function F defined as: $F = \sum dWi/Wi$, where dWi - impulse, Wi - characteristic velocity of the i-th satellite. The use of this function allows to distribute fuel consumption homogeneously between all satellites. The total energy costs and the required number of impulses of the relative station keeping are considerably lower than those of the absolute keeping.

The general computational scheme allows to optimize the motion of a constellation as a whole also in the case when some satellites perform maneuvres to transfer from one point to other (from injection orbit into final orbit, or from one operative point into another). In this case, numerical-analytical algorithms for determination parameters of optimal rendezvous are used.

The maneuvre schedule computation doesn't require considerable time expenditures because the satellite motion prediction based on the THEONA theory ensures both needed accuracies and high rapidity of calculations.

OP.III.3: Quasi-static Motions of Viscoelastic Satellites in the Gravitational Field. Problems of Stability and Nonlinear Oscillations

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We consider a motion of viscoelastic satellite. Assuming that the stiffness of the spacecraft is large and the dissipation parameter is small enough, we study the quasi-static motion, which is set after free elastic oscillations have damped. We describe an approach to construct and investigate the equations of quasi-static motion. The approach is a synthesis of the normal mode method and asymptotic methods. As an example we study planar quasi-static motions of a rigid body with a thin viscoelastic circular ring attached at some point of the body. In particular, the stability of the equilibrium positions in a circular orbit as well as the stability of eccentricity oscillations in a weakly elliptic orbit is investigated. Steady-state motions in the weakly elliptic orbit are also found and the conditions of their stability are given.

PP.5: Dynamics of the Planet Shells: New Problems of the Celestial Mechanics and Applications

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New generalized treatment of the n body problem has been suggested. Every body is the define system of the mutually interacting shells. In general case these shells are non-spherical and non-homogeneous. They also are considered as individual celestial bodies interacting one to another and with external bodies shells. In dependence from the studies the sells are considered as rigid bodies or deformable bodies with define physical properties and structure, are took into account the elastic and inelastic shell interactions, some from shells can be liquid, or gaseous, or empty. The wide class of the problem is concerned of the study of the small relative motions of the shell centers of mass and they slow relative rotational motion for the every body-system together with classical aspects of the problem on the study of the translational-rotational motions of the body-system. In cases of the empty, gaseous and liquid shells the assumption about small displacements of the shell centers of mass and they slow rotation is not necessary. The new treatments of the problem have place practically for all fields of the celestial mechanics (theory of attraction, developments of force functions, equilibrium of the liquid gravitating bodies, n body problem and others) and have very important meaning for geodynamics and planet dynamics of the Solar and Extra-Solar systems. The developments of the force function of the inner variant of two body problem were constructed in coordinates and in Andoyer-Delone variables. The problem about variations of the inner Earth mantle potential due to tidal attraction of the Moon and Sun has been solved. The stationary solutions of the inner variant of the two body problem and their stability were studied (case of the empty cavity and with consideration elastic interactions of the body). Translational oscillations of the spherical rigid core into liquid core have been studied. The small relative oscillation of the two shells of the body (the Earth) in the gravitational field other two point-bodies (the Sun and the Moon) were studied on the basis of the restricted four-body problem. A elastic shell interaction and real properties of the lunar (and solar) orbit were took into account. These and other results about mechanism of the relative displacements of the Earth shells have been used for important applications in the geodynamics and planet dynamics. The observed paleomigration of the Earth pole, the non-tidal deceleration of the Earth diurnal rotation were explained. The migration of the Earth centre of mass in geological time-scale was predicted. The observed long-periodic perturbations in the Earth pole motion were explained by the long-periodic variations in the Earth envelopes position and similar variations of the geopotential were found. The phenomena of the synchronism , cyclicity , inversion of the geophysical and geodynamical processes and phenomenon of the general rhythms of the shell-bodies of the solar system were discovered. The non-tidal acceleration of the Earth rotation, pole motion and secular variations of the coefficients of the zonal harmonic of geopotential were obtained theoretically in good agreement with observation data.

OP.I.3: Progress of the Perturbation Theory of the Attitude Dynamics

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The problem of constructing the analytical theory of the rotational motion of the Earth had one from central place in celestial mechanics. Starting from classical papers on this subject the equations of rotational motion in the osculating elements similar to Andoyer and angle-action variables have been used (Laplace,1825; Pontecoulant, Tisserand,1891; Andoyer, 1923; et. al.). But by construction of the force function of the problem in these variables authors as usually used the approximate developments using additional assumption about small eccentricities of the ellipsoid of inertia. Analytical solution of the problem had restricted character. In Kinoshita paper (1977) by construction of the Earth rotation theory similar simplifications were used (only constant of precession was presented in explicit form in term of elliptic integrals). Full formulae for first-order perturbations of the rotational motion of the satellite (Earth) in the gravitational field of the perturbing body (the Moon and the Sun) in angle-action variables (for Euler and Euler-Chandler unperturbed motions) were constructed (Barkin, 1993, 1998; Ferrandiz, Barkin and Getino, 1995). Amplitudes of the all perturbations of the first order were presented in terms of the elliptic functions and integrals of the action variables. It means that the analytical theory is applicable for study of the attitude motion of the natural and artificial celestial bodies with arbitrary dynamical structure. We have adopted similar theory for study of the rotation of the deformable celestial bodies. The new form of the canonical and non-canonical equations in Andoyer and angle-action variables were suggested. These variables were introduced on the basis of the integrable Euler-Chandler problem about attitude motion elastic body deformed by its own rotation (Ferrandiz, Barkin and Getino, 1995). Unperturbed motion takes into account the elastic property and reduced to the classical Euler-Poinsot problem but with special changed principal moment of inertia. The properties of the Earth Euler-Chandler unperturbed motion were described in details (Chandler period, eccentricity of the pole trajectory, non-uniform pole motion and others). The problem about rotation of the isolated deformable body with changeable in the time shell was studied. The components of the shell tensor of inertia are definite conditionally-periodic functions of the time. The analytical formulae for the secular and periodic perturbations were obtained in Andoyer, angle-action and classical Euler variables. In general these formulae were obtained for arbitrary parameters of the considered unperturbed motion (for example for arbitrary unperturbed value of the angle between angular moment and polar body axis). The observed pole drift and acceleration of the Earth diurnal rotation in the last century were explained on the basis of this solution by mechanism of the relative small oscillations of the Earth lower and upper shells. New analytical formula was obtained for tidal deceleration of the Earth. Tidal perturbations of the pole motion and diurnal Earth rotation were tabulated. The analytical formulae for the precession constant and add terms to the Chandler period and diurnal rotation due to gravitational attraction of the Moon and Sun were obtained in terms of the elliptical functions and integrals. The perturbation theory of the Earth rotation was constructed in the elastic Andoyer variable and angle-action variables. Perturbations of the Earth rotation due to the tidal and non-tidal variations of the Earth tensor of inertia in gravitational field of the Moon and Sun have been obtained.

PP.6: The Improved Model of Potential for Irregular Bodies.

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The potential of a small irregular body is usually approximated as the potential of a triaxial ellipsoid having no simple analytical form, or by means of spherical harmonics expansion which may be divergent near the body's surface. We propose the model of the potential generated by two massive straight segments. A similar model, based on one segment, was studied by Riaguas et al. (1999). Their model, however, properly represents only a single family of spheroids with the particular value of $b/a \approx 0.456$, regardless of the segment's mass and length. Combining two segments we can well approximate any ellipsoid, if one of the segments is allowed to have an imaginary length. The model has a simple analytical form and we show, that it well describes the potential of an irregular body, even close to its surface.

PP.48: A Semi-Analytical Model for Proper Elements of the Trojan Asteroids

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In this communication we present a method for the estimation of proper elements for asteroids located in tadpole orbits around the equilateral Lagrange points of the Sun-Jupiter system. The method employed is based on an asymmetric expansion of the Hamiltonian (in canonical variables) for the restricted three-body problem, in the vicinity of the 1:1 mean-motion resonance. As additional perturbations, we included the secular variations of Jupiter's orbit, as well as direct perturbations from the remaining exterior planets. A solution of the resulting system is then obtained by means of the so-called Henrard's Method (Henrard, 1990, *Cel. Mech. & Dynam. Astr.*, **49**, 43-67).

As results we present values of the proper elements (in the space of canonical momenta as well as in orbital elements a, e, i) for a set of real Troyan asteroids. These are then compared with the values obtained by Milani (1994, *Cel. Mech. & Dynam. Astr.*, **57**, 59-94).

OP.X.6: Planetary Rings with Shepherds: Generic Aspects

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We consider the system of planetary rings with shepherds as a reduced four-body problem neglecting interaction between ring particles. A scattering billiard model is introduced in this context to show that the appearance of stable narrow rings is generic for such systems. A saddle-center bifurcation is responsible for the relevant appearance of elliptic regions in phase space, that will generally assume ring shapes in the synodic frame, which in turn will precess in the sidereal frame. The generic character of this mechanism, as well as the extension to the case involving $1/r$ potentials is discussed.

OP.VIII.2: A Quantitative Approach of the Orbital Uncertainty Propagation through Close Encounters

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The greatest impediment against collisional predictions of NEOs is their orbital uncertainty and its divergence in time. Repeated close encounters with terrestrial planets generate chaotic motions which make unpredictable the future orbits of these objects. This paper deals with a quantitative analysis of orbital uncertainty propagation through repeated close encounters. We approach this problem analytically and numerically. Using the Opik's formalism on close encounters (motion is divided into two regions: inside and outside of the Hill's sphere of action) and making use of extensive symbolic computations we evaluate the post-encounter difference between two orbits, initially very close. We highlight critical orbits for which the uncertainty propagation takes place faster. In our numerical approach, we evaluate the orbital dispersion in the phase space of orbital elements for various encounter scenarios through a Monte Carlo simulation. A Runge-Kutta-Radau 15^{th}-order integrator is used. We emphasize the progressive degradation of orbital uncertainty from one encounter to another. The reliability of Lyapunov characteristic exponent and of the orbital D-criterion in evaluating the frequency of close encounters is discussed.

OP.X.5: A New Solution for Moon's Planetary Perturbations

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Comparisons of the semi-analytical solution ELP2000-82B (M. Chapront-Touzé, J. Chapront) of the lunar orbital motion to numerical integrations of the Jet Propulsion Laboratory and to observations of the Lunar Laser Ranging of the CERGA, have shown deficiencies resulting mainly from planetary perturbations series computed twenty years ago. Numerical complements are then introduced to improve the solution.
The aim of the computation of a new solution for planetary perturbations is to reduce the contribution of these complements. A new planetary solution VSOP2000 has been undertaken by X. Moisson (IMCCE-BdL) Besides, improvements in numerical tools should contribute to improve the precision of our series. We present here the results of our computation and comparisons to ELP2000-82B planetary perturbations solution and to JPL numerical integration DE403.

OP.IV.3: Orbit Determination Using Satellite Gravity Gradiometry

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The Satellite Gravity Gradiometry is a observation technics, which enables determining of the second derivatives of the Earth's gravity potential. They can be used for example to improve the orbits of satellites, to obtain their attitude and coefficients of the Earth's gravity field.

In the first part of this report we present a short description of the orbit determination method using measurements of the gravity gradient tensor components. These components are the functions of the gravity field coefficients and the gradiometric satellite position. It allows to make a system of the linear observation equations where the influence of the gravity field coefficient is neglected. Using the least squares adjustment method it can be obtain the normal equations, from which the corrections to the initial state dynamic vector components are estimated. The corrected initial state dynamic vector enables determining of the more accurate satellite orbit by means of the numerical integration method.

The report second part contains the simulation results of the determining orbit process using the simulations of the gravity tensor components. The various variants computation results are compared and some practical conclusions are given.

PP.8: Tidal and Rotational Effects in the Long–time Evolution of Hierarchical Triple Stellar Systems

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A new numerical integrator was developed by the author for studying the orbital evolution of hierarchical triple stellar systems. The code includes both equilibrium and dynamical tide approximations. (The later allows rotation with arbitrary rate around arbitrary direction of rotational axes.) First runs show that close triple systems containing distorted stars (e.g. eclipsing variables) could remain stable even in those cases when the mass–point model would predict the dissolution of the system (due to e.g. Kozai resonance). The long–term variation of the orbital elements (e.g. the inclination of the close (eclipsing) binary) and its observational consequences according to the mass–point and distorted models will be also compared. Finally the effect of an inclined rotational axis is also illustrated.

OP.VI.4: Lunisolar Resonances Revisited

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The lunisolar resonances may occur in the motion of Earth artificial satellites due to commensurabilities between the mean motion of the Sun or the Moon with the precession rate of a satellite's nodes and apsides, induced by the geopotential. The resonances were first indicated by Musen in 1960, but during the last 40 years the problem was treated only occasionally and in a quite selective manner. The present contribution reports recent studies by the author. The problem is simplified by imposing the Hill's approximation on the third body's perturbations. All apsidal and nodal-type resonances are identified and treated with a pendulum approximation. An example of a more refined analysis is given for one exemplary case. The resonances' overlapping zones are located and it is shown, that they may lead to a long-term chaotic evolution of satellites' orbits.

OP.XII.2: The Peculiar Orbit of Vysheslavia: Further Hints for its Yarkovsky Driven Origin?

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The orbit of the asteroid 2953 Vysheslavia is presently locked in a tiny chaotic zone very close to the 5:2 mean motion Jovian resonance. Its dynamical lifetime is estimated to be of the order of only about 10 Myr. Such conclusion poses a problem, since Vysheslavia is a member of the Koronis family which is most probably about 1 Gyr old. Two main hypotheses were developed to solve this apparent contradiction: (i) Vysheslavia might be an outcome of a recent secondary fragmentation event in the family, or (ii) Vysheslavia might have been placed on its peculiar orbit by a slow inward–drift of the semimajor axis due to the Yarkovsky effect. Though we cannot disprove the first possibility, here we bring more evidence for the second scenario. Most importantly, we have identified three more asteroids (likely members of the Koronis family) that have the same metastable orbit as Vysheslavia. However, more observations (astrometric, photometric and spectroscopic) are needed to firmly conclude about the past history of these interesting objects. The results might then have a more general implications about the fate of the asteroid families close to the principal resonances in the main asteroid belt.

PP.28: Primordial Sculpting of the Region of Semimajor Axes Smaller than 2 AU

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We carried out a series of numerical simulations of the dynamical evolution of test particles in the region between a=1.5 AU and a=1.9 AU, during the early phase of planetary formation in the Solar System. We explored two different scenarios: 1) only Jupiter and Saturn are present, including a case simulating the accretion of these planets and 2) including also Mars and the Earth. We found that only those asteroids from well defined narrow regions in semimajor axis, associated to the V16 secular resonance and the 5:1 mean motion commensurability with Jupiter, can reach Mars crossing orbits in time scales comparable to the time scale of formation of the inner planets. This implies that only a small fraction of objects in this region could have been contributors to the accretion of the inner planets. Secular resonances with the inner planets and mean motion commensurabilities with both the inner and the outer planets play a key role in the primordial sculpting of this region. We also computed the intrinsic probability of collision with Mars, concluding that primordial asteroids from this region did not contribute in a significant way to the early strong bombardment of Mars' surface.

PP.9: The Method of Close Returns in the Restricted Kokoriev-Kirpichnikov Problem

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The method of close returns is a simple qualitative tool providing the information about the evolution of a dynamical system with an arbitrary number of degrees of freedom. It can be seen as a simplified version of the frequency analysis approach. The method was invented by Mindlin and Gilmore (1992, *Physica D*, **58**, 229) but the only case of its application in celestial mechanics remains still the study of the Hyperion's rotation (Boyd et al., 1994, *Ap. J.*, **431**, 425). We test the performance of the method in the restricted problem of Kokoriev and Kirpichnikov, i.e. the orbital motion of a negligible point mass in the field of a rotating dumb-bell. In this three degrees of freedom problem, the method behaves very well; it allows to make a clear distinction between the chaotic and quasi-periodic orbits.

OP.XIII.3: Short Arc CCD Observations of Celestial Bodies: New Approach

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A domination of CCD technique in modern Astrometry leads to inspection of a role and meaning of crowded celestial body positions obtained by a single small telescope during one night's hours and consequently distributed along supershort topocentric arc. Now positional CCD observations allows us to get asteroid coordinate sets with any time density and processes them in interactive mode. Such observational data consists an important information as to space motion of observed asteroid, namely the Parameters of its Apparent Motion (AMP), i.e. its topocentric angular velocity μ and acceleration $\dot{\mu}$, positional angle ψ and curvature C of its trajectory. These values are calculated with statistical treatment of the CCD positions by means of time polynom approximation for each α, δ coordinate set. The AMPs were taken into consideration by Pulkovo astronomers with the beginning of the first Artificial Earth Satellite photographic observations. In Pulkovo observatory the new Apparent Motion Parameters Method was developed by Dr. A.Kiselev and his colleagues to determine initial elliptical orbit of observed celestial body on the base of parameters (α, δ, μ, $\dot{\mu}$, ψ and C). Our AMP-method that is a further developing of the classic Laplacian orbit determination method was successively applied for an investigation of the AES, Space Debris, small Solar System bodies and Double Stars.

The epoch of supremacy of CCD technique, the composition of the rich and accurate star catalogues and Pulkovo investigations of the super short arc information allows us to elaborate the new approach to the solution of the problem of observations of any celestial body moving on the background of stars. It is a fast analysis of CCD observations of moving object, its preliminary orbit determination and object's identification with orbital catalogues or, if an object is not known, further CCD observations with the use of ephemerides calculated by means of the Pulkovo AMP-method in an interactive mode.

The algorithms and software were developed in Pulkovo observatory for the fast analysis of any CCD frame where the moving celestial objects could be detected. Due to this approach we can get also new information for Celestial Mechanics as "by product" of dominating astrophysical CCD observations.

PP.10: Astrometric Accuracy of the Kuiper Belt Asteroids CCD Observations

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About 2500 astrometric positions obtained during 1992-1999 by world observatories for the Kuiper Belt objects were analysed with the help of EPOS software package created at the Pulkovo Astronomical Observatory. Real CCD observations of these objects were taken from the MPCs.

The accuracy of observations was estimated by studing the dispersion of the average (O-C) for each type of observation obtained by each telescope. A representative sample of the considered observations was statistically reliable. The star catalogs GSC and USNO were used by most of the observers for astrometric reduction of their CCD-frames.

The results of Internal and External accuracies of observations are given for each observatory and each telescope. Usually, the Internal accuracy of a single positional CCD observation for the large telescopes is +/–0.10" (obtained during single night) and External accuracy is +/–0.20" (obtained by statistical treatment of the CCD positional observations during several successive nights).

OP.VII.1: An Alternative Theory of Asteroid Dynamics (Size and Lifetimes of Asteroidal Resonances – Application of Complex Spectral Analysis)

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We obtain the size and lifetimes of some asteroidal resonances in the frame of the three-body problem Sun-Jupiter-Asteroid using the complex spectral analysis, developped by Brussels-Austin group dirrected by Nobel prize laureate Prof.Ilya Prigogine .Application of this new alternative theory to classical three-body problems permits to overcome the so called by Henry Poincare "Big difficulty of Celestial Mechanics"-small denominators. The breaking of time symmetry in the hearth of Celestial Mechanics leads to important discussion on principle of causality and predictability in modern celestial mechanics.

OP.IX.4: Dynamically New Comets in the Solar System

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We present the results of some numerical studies on the dynamical history of selected long period comets. In our investigations we include all comets with orbits of good quality. We calculated barycentric, *original* orbital elements for comets at a distance of 250 AU from the sun and then we followed the motion of each comet backward to its previous perihelion passage (elliptic orbit only) including the galactic perturbations using two different models. In a similar fashion we traced the past motion of hyperbolic comets. The influence of the stellar perturbations is also discussed. We present some implications for the cometary origin and compare several, previously published statistics with the current population of long period comets with well defined orbits.

OP.I.1: On the Attitude Dynamics of Perturbed Triaxial Rigid Bodies

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Attitude dynamics of perturbed triaxial rigid bodies is a rather involved problen, due to the presence of elliptic functions even in the Euler equations for the free rotation of a triaxial rigid body.

We revisited the Euler-Poinsot problem, and present several sets of canonical variables as well as its integration. With the solution of this problem, that will be taken as the unperturbed part, we expand the perturbation in Fourier series, which coefficients are polynomials of the Jacobian nome. These series converge very fast, and thus, with only few terms a good approximation is obtained. Once the expansion is performed, it is possible to apply to it a Lie-transformation. Several application to artificial and natural bodies have been carried out.

With the solution of the unperturbed problem, other aspects, like transversal homoclinic orbits and stochasticity bands are also considered.

OP.II.6: Solving a Gylden–Meščerskij System in Delaunay–Scheifele–Like Variables

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We deal with the *nonstationary two–body problem* in Hamiltonian formulation.

A *Gylden system* (Deprit 1983, *Celest. Mech.* **31,** 1–22) is a two–body Kepler problem in which the Keplerian coupling parameter $\mu \equiv \mu(t)$ undergoes variations in time.

In some previous papers (Floría: *Celest. Mech. and Dyn. Astron.* **68,** 1997, 75–85; *Impact of Modern Dynamics in Astronomy*, Proceedings of the IAU Colloquium No. 172, Namur, Belgium, July 1998, pp. 461–462, Kluwer 1999, Henrard & Ferraz–Mello, Eds.), inspired by the treatment of time–varying Delaunay transformations due to Deprit (1983, §3), we considered time–dependent canonical transformations of the TR–type in extended phase space (Deprit 1981, *Celest. Mech.* **23,** 299–305) that generalize the classical transformations to Delaunay–Scheifele (DS) variables (originally devised to reduce perturbed, stationary, Keplerian systems.) We applied these mappings to a generic Hamiltonian characterizing a class of perturbed Gylden–like systems reduced to the orbital plane.

As a further development of our previous analytical considerations, we study the solution of a non-stationary two–body problem, with a time–varying gravitational parameter $\mu(t)$. We restrict ourself to the consideration of $\mu(t)$ subjected to variations according to the Meščerskij's laws, in which case the problem is known to be integrable.

The mathematical law of change of μ known as the *first Meščerskij law* leads to the integrability case of Gylden systems most often considered in Celestial Mechanics. This integrable and integrated model, with exact analytical solution, has been thoroughly analyzed, and can be used as a first approximation in the investigation of more complicated perturbed Gylden systems.

Due to the significance of the Gylden–Meščerskij problem in astronomical, astrophysical and cosmological studies (e.g., isotropic mass loss in binary or multiple star systems), and as a preliminary step prior to the treatment of problems of perturbed motion involving time–dependent gravitational–type systems, described as *perturbed Gylden problems*, we find it interesting and appropriate to complete the picture by developing the corresponding study and solution in terms of canonical variables within a generalized DS–type formulation.

Key Words: nonstationary two–body problem, time–varying Keplerian coupling parameter, Gylden systems, Meščerskij's laws, Delaunay–Scheifele–like canonical variables, uniform treatment of two–body motion.

OP.XI.1: Analysis of the Validity of the Fast Lyapunov Indicator to Study the Structure of Symplectic Mappings. Application to the Transition from Nekhoroshev Regime to the Chirikov one.

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It is already known [1] that the Fast Lyapunov Indicator (hereafter FLI), i.e. the computation on a relatively short time of the largest Lyapunov indicator, allows to discriminate between ordered and weak chaotic motion. We have found that, under certain conditions, the FLI also discriminates between resonant and non resonant orbits, not only for two dimensional mappings or conservative Hamiltonian systems with two degrees of freedom but also for higher dimensional ones. Using this indicator we present an example of the Arnold's web detection for the 4 and 6 dimensional standard symplectic maps. Using the FLIs we determine for both symplectic mappings and Hamiltonian systems the critical value for which the system goes from the Nekhoroshev regime to the Chirikov one.

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OP.VIII.3: Prediction, Observation and Analysis of Asteroid's Close Encounters

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Masses of large asteroids are needed for improving the modern planetary ephemerides. As the asteroids are so small, the best method to obtain their masses is through observations of individual encounters between pairs of asteroids. 239 minor planets with diameter bigger than 100 km have been selected for mass determination through close encounters with numbered and unnumbered asteroids. The orbits of 11000 numbered and 35000 unnumbered minor planets in the time interval 1985-2010 have been integrated and rectangular co-ordinates stored every ten days. For each one of the 239 large asteroids, a filter is applied to select objects with some possibilities of a real encounter. Close encounters are detected from distance and relative velocity values between both asteroids and several parameters are calculated for each encounter. The possibility of observing the asteroids at the epoch of their encounter is analysed. The relation between the accuracy in the mass determination and data distribution is also investigated.

PP.13: NEO Observation Program at Astronomical Observatory in Modra

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A basic information about aimed NEO Program, as a part of astrometric observations at Astronomical Observatory in Modra, is presented. Its goals and results obtained up to now are summarized. Further progress of the program is indicated, also.

OP.VI.2: Near-Earth Asteroids Close to Mean Motion Resonances: the Orbital Evolution

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The movement of asteroids near mean motion resonances is considered in the paper. Results of study of orbital evolution of NEAs 3838 Epona, 1996 DH, 1996 AJ1, 1994 RB, 2608 Seneca are presented.

Equations of the motion of asteroids have been integrated numerically. In process of numerical integration perturbations from planets (except Pluto) and Moon have been taken into account. The interval of time is ranging from -3000 years to 3000 years. Initial elements of orbits of asteroids have been taken from catalogue of E. Bowell, with date of 22.01.99 (ftp://ftp.lowell.edu/pub/elgb/astorb.dat). The motion of each object has been considered in two coordinate frame: 1) heliocentric frame related to ecliptic and equinox 2000.0; 2) heliocentric frame rotating with angular velocity of the planet with which the object is in a resonance.

Evolution of ensembles of 100 test particles with orbital elements nearby those of nominal orbits has been considered for each object. The initial set of orbits has been generated on the basis of probable variations of their initial orbital elements received from the least square analysis of observations. Numerical estimates of the average rate of deviation of initially nearby trajectories have been computed.

Investigations were carried out with the help of the specially developed software package, which allows to predict the motion of asteroids with high-accuracy. There is opportunity to using various forms of the differential equations and various coordinate frames in this package. The package has convenient interface and allows to represent the motion of asteroids and planets graphically. The package is created by using developing tool Delphi.

OP.III.2: THEONA, New Version: An Efficient Tool for Orbit Dynamics

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The Numeric-Analytical satellite theory has been elaborated to support different problems of applied celestial mechanics and space flight dynamics: orbit determination and prediction, maneuver optimization, model parameters determination, planning and designing of satellite mission, mission analysis etc. The software based on this theory are realized and approved during 10 years of works in the Ballistic Center of the Keldysh Institute of Applied Mathematics, the Russian Academy of Sciences. Now I develop a new version of software called THEONA. It provides fast calculations with good accuracy for wide class of satellite orbits on orbit dynamics problems.

The THEONA's scheme combines methods of analytical integration and quadrature formulae. To integrate analytically it use special functions: well-known (Jacoby functions, Legendre functions, Newcomb polynomials) and new functions I proposed. Hansen coefficients are a particular case of these new functions. Analytical integration takes into account all essential perturbations: gravity field (any number of harmonics), air drag (full standard models of atmospheric density), third body attraction (using DE405/or DE403/or DE118 ephemerides), solar radiation pressure with shadow effects. Besides, using methods with quadrature formulae we can to take into account more accurate dynamical model of satellite motion (other perturbations, maneuvers with different duration).

THEONA is valid tool for many orbit dynamics problems, e.g. space flight control of orbital station and spacecrafts, satellite constellation keeping and formation, space object observation and identification etc. Some examples of using THEONA are presented in this paper.

OP.V.4: Optimal Maneuver Schedule for Constellation Keeping and Formation

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Problem of satellite configuration keeping and formation is considered. Proposed method of problem solution provides to maintain the motion of satellite system during long time interval: from some days to 1 year.

Needed accuracy is supported by using an iteration procedure. The base of this procedure is analytical determination of impulses parameters and high efficient THEONA software based on the Numeric-Analytical satellite theory. Computing time of maneuvers parameters calculation have near linear dependence from number of satellites.

We consider also the problems of satellite constellation formation and of spacecraft transfer from one working point of constellation to other.

An optimization of the motion of satellite system is provided in this case also.

PP.14: Lyapunov Stability of the Triangular Libration Points in the Unrestricted Planar Problem of a Symmetric Body and a Point Mass in Resonance Cases.

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In papers by Goździewski and Maciejewski (1998-2000) which extend results by Kokoriev and Kirpichnikov (1988), we investigated unrestricted, planar problem of a symmetric rigid body and a sphere. Here we are focused on the analytical study of nonlinear stability of the triangular equilibria arising in this model in low-order resonance cases.

The system may be considered as physically acceptable approximation of the two rigid bodies problem. Simultaneously it is described by a very simple Hamiltonian. Moreover it has reach consequences, which was shown already in the papers mentioned, e.g., in its restricted version (when the point mass vanishes) generalizes two well known classical problems of Celestial Mechanics: the planar, restricted three body problem and the Euler problem of two fixed centers.

One of our goals is to demonstrate that studies of nonlinear stability of the model triangular equilibria cover almost all the possible theoretical cases present in a two degree of freedom Hamiltonian system. We believe that it justifies again its theoretical importance.

OP.XIV.4: Resonant Excitation of Spiral Density Waves in Galactic Disks

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Linear kinetic theory is developed to describe the resonant Landau-type excitation of spiral density waves in a self-gravitating, rapidly and nonuniformly rotating, spatially inhomogeneous, and practically collisionless stellar disk of flat galaxies. The system is treated by employing the well elaborated mathematical formalisms from plasma perturbation theory using normal-mode kinetic analysis. It is shown that the kinetic wave–star interaction at the corotation resonance in a hydrodynamically stable nonuniformly rotating disk of particles resembles a Cherenkov emission of electromagnetic waves (light) with continuous spectrum and specific angular distribution by an electric charge moving in a medium at a constant velocity. This Landau excitation of spiral density waves is suggested as a mechanism for the formation of observable structural features such as spiral arms, and the slow on a Hubble time dynamical relaxation of disk-shaped galaxies, in a parameter regime of classical "hydrodynamical" Jeans stability. A separate investigation based on extensive parallel N-body computer simulations is described to determine experimentally these Landau-growing, oscillatory propagating collective modes of oscillations.

PP.15: Modern Problems of the Physical Libration of the Moon

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The certain detection of the Lunar free libration parameters with significant dissipation by LLR analyses, geophysical data about lunar interior after Apollo (dissipation factors Q), Clementine (tomography of lunar internal structure) and Lunar Prospector (pole ice lakes and "mascons") impose heavy demands on analytical description of the Lunar interior models. Most of fine effects of the physical libration of the solid Moon were considered by Eckhardt (1981), Moons (1982, 1984) and by Chapront & Chapront-Touze (1997, 1998). Effects of the free libration were investigated by Calame (1977), Yoder (1981), Eckardt (1993); Newhall & Williams (1997). An action of the lunar core on the PhLL is analyzed by Yoder (1981), Dickey et al. (1994), the core-mantle differential rotation is considered by Williams et al. (1998, 1999), by Petrova & Gusev (1998) the free core nutation of the Moon is calculated by Petrova & Gusev (1999), of the Mars – by Souchay & Bouquillon (1998), Dehant et al. (2000). It is proposed, that, the further development of the analytical theory of physical libration of the visco-elastic multy-layer Moon will be carried out in the following directions:
- a development the model of two-layer convective dissipation Moon in the frame of Hamiltonian approach with the generalized forces;
- investigation of the core-mantle differential rotation as the source of internal heating and of maintaining of free libration;
- a creation of the modern high-precision analytical tables of physical libration of the Moon and of the "Lunar annual".

PP.16: Observational Effects of the Lunar Core-mantle Differential Rotation.

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The differential rotation of the rigid mantle and liquid core in the Moon, the interaction between them is responsible for the formation of specific transition zone - core-mantle boundary that play an important role in observed phenomena. Seismic data obtained from Apollo mission give the magnitude of dissipative factor $Q \sim 1000$ fast greater than that from LLR analyses $Q \sim 26$. Solid tidal friction does not explain the great rotational dissipation. There are serious validity for the proposal about important role of the core-mantle processes on the rotation of the Moon. Dissipative effects arising from the core-mantle interaction are responsible for additional heating of the planet's interior, causing convective motion in the mantle and grows of the lunar lithosphere; for the exciting and maintaining of free librations in the Moon; for arising of plumes that are responsible for the formation of possible hot spots and "mascons" in the crust. We propose that "mascons" in the thick lunar continental crust might be produced by convective processes in the upper mantle of the Moon at the early stage of its thermal evolution If proposed hypothesis is true, the specific surface characteristics should be observed:
- the pluton-like intrusions ("mascons"),
- specific fluctuations of thermal ("warm spot"), gravitational fields,
- the Moho uplifts,topographic features in the form of arched lineament. In the frame of the Hamilton approach, by analyzing of the differential rotation equations of two-layer Moon composed of the rigid mantle and liquid core we have obtained the period of the free core nutation equal to 144.73/yr. We have also estimated the differential core-mantle rotation rate equal to 2.4 degree/yr. In this connection many new cosmic experiments - Lunar A, Euromoon, SELENE, SMART - will give a possibility to determine the size and composition of a lunar core, the magnetic and heat characteristics of the Moon.

OP.I.2: Attitude Dynamics of Orbiting Gyrostats

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Equilibrium attitudes of a rigid satellite with N rotors in a central gravitational field are investigated. Over the past century, an understanding of the torque-free motion of gyrostats has been developed in cases with freely spinning rotors or with rotors constrained to spin at constant speed relative to the platform. Equilibrium motions of orbiting gyrostats, where the gravity gradient torque is included, have been studied for circular orbits. The gravitational moment used in most studies is obtained by truncating the gravitational potential in an inconsistent manner. In previous work by the author and colleagues, the inconsistency has been shown to be negligible for "ordinary" asymmetric, rigid, gravity-gradient spacecraft, but the relevance of this work for gyrostats has not been investigated thoroughly. Furthermore, most results are for spacecraft with free or constant-speed rotors. During rotational maneuvers, the rotors satisfy neither of these conditions. Although many have studied problems of maneuvering gyrostats, virtually no one has used information about equilibria to develop reorientation control laws. Herein, we attempt to unify the various cases, while taking into account more accurate approximations of the potential. The equations of motion are written as a noncanonical Hamiltonian system, where the Hamiltonian includes the potential, a volume integral over the body of the gyrostat. In practice, the Hamiltonian is approximated to partially decouple the position and attitude equations. The equilibria of this system of equations represent the steady motions of the body as seen in the body frame, and correspond to stationary points of the Hamiltonian constrained by the Casimir functions. This defines an algorithm for computing equilibria. In contrast to other approaches, this algorithm provides stability information directly, since the calculations required to solve the constrained minimization problem are also involved in computing the positive definiteness of the Hamiltonian as a Lyapunov function.

PP.7: Nonlinear Stability in Generalised Photogravitational Restricted Three Body Problem

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We have discussed the non-linear stability of triangular equilibrium point in generalised photogravitational restricted three body problem.The problem is generalised in the sense that the both primaries are taken as an oblate spheroid.We performed the first order and second order normalisation of the Hamiltonian of the problem.We have applied Arnold's theorem to examine the condition of non-linear stability.We have found three critical mass ratio where this theorem fails. The stability condition is different from the classical case due to radiation and oblateness of both primaries.

OP.VI.3: Second Fundamental Model of Resonance with Asymmetric Equilibria

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In 1994, Beauge presented a general analysis of the planar restricted three- body problem in the case of exterior resonances. Taking the Andoyer Hamiltonian in which harmonics up to order 2 are considered, he pointed out that asymmetric equilibria could appear in these resonances for many commensurabilities. The aim of our paper is to study the characteristics of the phase space using a semi-numerical method to compute the hamiltonian function. the new model can be seen as a extension of the second fundamental model of resonance (1982) : we also calculate critical curves and probabilities of capture.

PP.17: Moon-Earth Separation Problem in the Dynamics of Near Earth Asteroids

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The number of discovered Near Earth Asteroids has dramatically increased in the last years. New observational data provide more informations for the dynamical studies of these objects. Important problem in the numerical studies of NEA motion is the estimation of possible perturbing effects. It is difficult to decide which effect can be neglected in in the integration. Our results often depend on 'subtle' perturbations caused by small or distant objects. One of significant sources of perturbations in the motion of NEA is the Earth-Moon system. Some authors take into account the barycentre of the Earth-Moon system as a single perturbing body, but in specific cases the separation of these bodies should be taken into account (especially, in the event of close ecounters).

The influence of the Earth-Moon system on the evolution of NEA was investigated in the following poster. The latest observational results and various integration methods were applied. The nature of perturbations caused by this 'binary' system was described and compared with the results obtained by using the 'barycentre model'. Additionally, the efficiency of several numerical algorithms was compared.

PP.18: MUNIN Attitude Determination by Image Processing Algorithm

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Nano-satellite MUNIN, scheduled for launch in April, 2000 is equipped by passive magnetic attitude control system. The primary purpose of this project is an Aurora observation and upper atmosphere particles behavior researching. It is passively stabilized satellite and its actual attitude information is essential for true data interpretation of on-board equipment. The method of satellite attitude determination by star constellation image processing algorithm is considered. Besides its accuracy it can give three-axis information by using just a single sensor, an on-board digital CCD–camera. An image gives the position of stars in the focal plane, that is, their coordinates in axes related with MUNIN. Using celestial coordinates of the same stars one enables to calculate the transformation matrix, which is in fact the matrix of actual satellite attitude position. Digital image is processed by a computer in such a way, that all stars are extracted and stored in a list with their position in the focal plane. These stars compose a constellation, which is compared with all possible constellations of a star catalog by special matching algorithm developed under these approaches. It seems at least four stars are necessary to identify an unambiguous attitude position with accuracy of 0.2°. Whenever the constellation has been positively and definitely identified, the celestial coordinates of two outermost stars can be used for actual three-axis satellite attitude information development. Because of comparably long computation time vectorization and preallocation were used to reduce matching time significantly. This method is especially recommended for inexpensive small satellites.

PP.20: Solar Wind and Motion of Meteoroids

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The effect of nonradial component of solar wind is discussed from the qualitative point of view. It is shown that the direction of nonradial component is opposite in comparison with the direction used in papers dealing with orbital evolution of meteoroids (Cremonese, G., Fulle, M., Marzari, F., Vanzani, V., 1997, Astron. Astrophys. 324, 770).

PP.23: Orbital Motion in Outer Solar System

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Motion of a point mass in gravitational fields of the Sun and of the galactic disk is studied. Fundamental features of the motion are found by investigating the time-averaged differential equations for orbital evolution. Several types of possible orbits are mathematically exactly derived in a strictly analytical way. The relation $a^3\ P^2 = f(e_0, i_0, \omega_0)$ between semimajor axis a and period P of the change of osculating orbital elements is found (the index 0 denotes initial values of the quantities).

Due to conservation of energy in potential fields a is a constant. Moreover, the component of angular momentum perpendicular to the galactic plane is conserved. Due to these facts the system of equations reduces to two equations for either (e, ω), or (i, ω) (the length of the ascending node does not enter the equations for a, e, i, ω and is not solved here).

PP.19: On the Poynting-Robertson Effect and Analytical Solutions

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Solutions of the two-body problem with the simultaneous action of the solar electromagnetic radiation in the form of the Poynting-Robertson effect are discussed. Special attention is devoted to pseudo-circular orbits and terminal values of osculating elements. The obtained results complete those of Klačka and Kaufmannová (1992) and Breiter and Jackson (1998).

Terminal values of osculating elements presented in Breiter and Jackson (1998) are of no physical sense due to the fact that relativistic equation of motion containing only first order of $\vec{v}/c$ was used in the paper.

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OP.XIII.2: Kuiper-Belt Objects: Distribution of Orbital Elements and Observational Selection Effects

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The influence of the observational selection effects in the set of the known Edgeworth-Kuiper belt objects is investigated. The most important observational selection effect is closely connected with the fact that discoveries of the objects were done i)near their orbital nodes, or, ii) objects with small inclinations are known. Concentration of perihelia of the known Edgeworth- Kuiper belt objects corresponds to the direction of vernal equinox. The decrease of the concentration in some region(s) may be caused by observational selection effects (together with the fact that greater part of objects with higher absolute magnitudes is observed). Radial distribution of EKOs in perihelion distance corresponds to constant linear density – this would suggest not ecliptically concentrated form of the cloud of EKOs.

PP.21: Meteor Orbits – Selection Criteria. I. Example of a Broad Meteor Stream Analysis

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Meteor stream membership criteria are applied to a broad meteor stream. The methods developed in Klačka (1999, submitted to Astron. Astrophys.) are applied to real data taken from The IAU Meteor Data Center in Lund. Various forms of areas in a phase space of orbital elements (and combinations of orbital elements) are taken into account. The results are compared and discussed. As a special case, the set of bolid meteors is found and investigated for the meteor stream.

PP.22: Meteor Orbits – Selection Criteria. II. Example of a Narrow Meteor Stream Analysis

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Meteor stream membership criteria are applied to a narrow meteor stream. The methods developed in Klačka (1999, submitted to Astron. Astrophys.) are applied to real data taken from The IAU Meteor Data Center in Lund. Various forms of areas in a phase space of orbital elements (and combinations of orbital elements) are taken into account. The results are compared and discussed. As a special case, the set of bolid meteors is found and investigated for the meteor stream.

Comparison of the methods of classifications for broad and narrow streams are discussed.

OP.VII.2: Multi-dimensional Fourier Transformation of Planetary Disturbing Function

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It is well known that Fourier expansions of planetary disturbing function can be computed numerically with the help of numerical Fourier analysis (see, e.g., Brouwer, D., Clemence, G.M.: 1961 'Methods of Celestial Mechanics', Academic Press, N.Y.). What is making this approach advantageous nowadays is fast computers and Fast Fourier Transformation (FFT) algorithm. The FFT algorithm has been introduced into modern practice by Cooley and Tukey in 1965. Retrospectively it has become known that the FFT algorithm was invented independently by a dozen of individuals starting from Gauss in 1805 (Heideman, M.T., Johnson, D.N., Burrus, C.S.: 1985 'Gauss and the History of the Fast Fourier Transform'. Archive for History of Exact Sciences, **34**, 265–277). It was exciting also to learn that Gauss has invented the algorithm to compute Fourier expansions of the planetary disturbing function. Most general 5-dimensional Fourier expansion of the planetary disturbing function in standard notations reads:

$$R = \frac{G\mathcal{M}'}{a'} \sum_{i=-\infty}^{\infty} \sum_{j=-\infty}^{\infty} \sum_{k=-\infty}^{\infty} \sum_{l=-\infty}^{\infty} \sum_{m=0}^{\infty} B_{ijklm}(\alpha, e, e', i, i') \cos(i\,M + j\,M' + k\,\omega + l\,\omega' + m(\Omega - \Omega')),$$

$\alpha = a/a'$ being the ratio of the two semi-major axes. Numerical Fourier transformation of R allows one to compute coefficients B_{ijklm} for any admissible numerical values of α, e, e', i, i'. Numerical computation of these 5-dimensional series has become feasible on a typical server-class computer quite recently. For practical calculations we used SGI Origin2000 with 48 R10000 processors running at 195MHz. On that computer we used up to 8Gb RAM for a single calculation. To give an example, in order to compute series (1) for the perturbations of Jupiter on Veritas ($\alpha \approx 0.609$, $e \approx 0.1009$, $e' \approx 0.0485$, $i \approx 9°16'$, $i' \approx 1°18'$) with an accuracy of 10^{-14} the FFT size should be taken as $56 \times 52 \times 48 \times 24 \times 208$ which is required about 5.4 Gb RAM and 30 minutes of computing time in single processor mode. In this example, the number of coefficients B_{ijklm}, absolute value of which is greater than 10^{-14}, is 1 083 126. Our experience shows that the numerical calculation even of the most general Fourier expansions of the planetary disturbing function is quite feasible and can become an useful tool of celestial mechanics in the nearest future. Further details and examples will be given in the presentation.

PP.26: Determination of Mass of Jupiter and that of Some Minor Planets from Observations of Minor Planets Moving in 2:1 Commensurability with Jupiter.

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Great number of observations of minor planets accumulated by now gives possibility to estimate once again the value of the Jupiter' mass from the minor planets being in 2:1 commensurability with Jupiter as proposed by Hill (1873). In so doing the perturbations from 9 major planets and 5 asteroids in accordance with coordinates/masses from DE200/LE200 ephemeris were taken into account. The relativistic terms due to the Sun and Jupiter were included in equations of motion. The observations were corrected for gravitational deflection of light and for phase effect by Lommel–Zeeliger law of scattering. 5896 observations of 13 minor planets were used in general solution for orbital elements of minor planets and mass of Jupiter. The comparison of obtained results with those of other investigations is given in the following Table.

Object of study	Sun-Jupiter mass ratio	Author
Pioneer & Voyager tracking data	1047.3486 $\pm$0.0008	Campbell and Synnott (1985)
Martian landers	1047.34830 0.00017	Pitjeva (1997)
Minor planets	1047.3482 0.0008	This paper

In the second part of present work the masses of some minor planets have been found from their gravitational perturbations on a number of smaller planets. The corresponding pairs of minor planets were chosen from those being in 2:1 commensurability with Jupiter. Sampling of the pairs was governed by criterion: minimal distance between planets is less or equal to 0.1 a.u. Usage of less stringent requirement than usually used 0.05 a.u. is here warrantable as the approaches of planets are regularly repeated due to commensurability and mutual velocities of the bodies are rather small. The obtained results are given below.

Perturbing minor planet	Mass (10^{-11} M_{Sun})	Perturbed minor planets	Number of observations
10 Hygiea	5.7$\pm$1.4	48,120,357,767,1974,2330,2846	1390
52 Europa	2.9 1.6	92,401,489,491,595,635,1015, 1489,1571,1674,2197,2405,2582	1803
65 Cybele	0.79 0.40	526,979,1082,1261,3036,3150,1815	1025

Thus, the approach proposed in this paper gives possibility to increase the number of minor planets whose masses can be determined with sufficient precision.

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Campbell, J.K. and Synnott, S.P. 1985. Astron.J., 90, 364-372.
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PP.25: Interaction of Stationary Nonspherical Interplanetary Dust Particle with Solar Electromagnetic Radiation

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Interplanetary dust particles are different in size, chemical composition, shape and physical-optical properties. The light scattering by such particles predetermines changes of their motion in the space. This fact is expressed by well-known radiation pressure, which was notoriously based on spherical target assumption. The only forward and backward scattering efficiencies are important in this case. However, any irregularity of the particle shape will produce certain momentum in perpendicular projections to the direction of light propagation. This may be caused also by inhomogeneity of particle chemical composition (or particle density). Particle shape specificity (unconcavities, cavities,...) plays dominant role in formation of light scattering diagram.

Numerical results of the interaction of solar electromagnetic radiation with stationary nonspherical small interplanetary dust particle are presented. Rapid rotation of the particle about defined axis of rotation is considered. The interaction significantly differs from the interaction between spherical particle and electromagnetic radiation. The importance of the results in application to Solar System is presented in our second contribution.

PP.24: On the Stability of the Zodiacal Cloud

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Motion of small nonspherical interplanetary dust particle (meteoroid) under the action of solar gravity and solar electromagnetic radiation is investigated. Rapid rotation of the particle about defined axis of rotation is considered.

Comparison of resulting particle motion with the well-known Poynting-Robertson (P-R) effect leads to significantly different conclusions. The P-R effect's deceleration term is in one to two orders in magnitude less important than terms corresponding to nonforward (or nonbackward) radiation scattering. Generally, it depends mainly on particle size, shape, and composition. While the P-R effect yields spiraling toward the Sun (decrease of semimajor-axis with time), motion of real meteoroid is much more complicated. Inspiraling toward the Sun during some time interval is followed by spiraling outward the Sun. This process can be repeated for many times. It could be essentially affected by chosen starting geometry of the solved system particle-Sun, i.e. by selected particle rotation axis, current particle orientation, and its position relatively to the Sun. Absence of any relation between semimajor-axis and eccentricity is a consequence of such problem complexity.

The results are important for application to the stability of Zodiacal cloud. While the P-R effect (valid for spherical particles) yields instability of the cloud due to monotonous inspiraling of the particles toward the Sun, our numerical simulations show that particle nonsphericity could radically modify its resulting motion in the Solar System. There was found a specific kind of particles characterized by the relatively stable trajectories. Therefore the particle source (comets, asteroids) is no necessary to explain the stability of dust envelope consisting of such bodies.

PP.27: Ephemeris Meaning of Parameters of Asteroids's Apparent Motion

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Method to solve an identification problem for moving celestial object was elaborated. It requires the object's coordinates α, δ and their two derivatives at given UT moment or the object's Apparent Motion Parameters: topocentric angular velocity μ and $\dot{\mu}$ acceleration, positional angle ψ and curvature C of celestial body trajectory. These parameters are calculated with polynomial approximation of dense CCD object positions observed along a short arc of its moving on the background of reference stars.

It was shown that these new parameters have a large ephemeris meaning and allow to identify the registered object in interactive mode within an time interval up to a few weeks. The EPOS and LAPLACE software packages developed at Pulkovo Astronomical Observatory were used to test and identify the asteroids observed during February 1999 by various world's observatories and published in MPC with preliminary numbers from 1999DA to 1999CA. The results obtained were compared with the identification of the International Minor Planet Center. Our method gave 16 new identifications in the considered data.

OP.V.5: Dynamical Systems, Three-Body Problem and Space Mission Design

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New space missions are increasingly more complex; demands on exortic orbits to solve engineering problems have grown beyond the conic-centered astrodynamic infrastructure. The delicate heteroclinic dynamics used by the Genesis Mission dramatically illustrates the need for a new paradigm: dynamical system study of three-body problem.

Furthermore, it appears this dynamics has much to say about the morphology and transport of materials within the Solar System. The synergistic interplay between the natural dynamics of the Solar System and applications to engineering has produced a number of new techniques for constructing spacecraft trajectories with desired characteristics.

Specifically, these techniques are used to construct a "Petit Grand Tour" of the moons of Jupiter. We have designed an orbit which follows a prescribed itinerary in its visit to the many moons (e.g., one orbit around Ganymede, four around Europa, etc.).

We also apply similar techniques to produce a lunar capture mission which uses less fuel than a Hohmann transfer. We decouple the Sun-Earth-Moon-Spacecraft 4-body problem into two 3-body problems. Using the invariant manifold theory of the Lagrange points of the 3-body systems, we construct low energy transfer trajectories from the Earth to the Moon with a ballistic capture at the Moon.

This is joint work with Martin W. Lo, Jerrold E. Marsden and Shane D. Ross.

OP.IV.2: Influence of the Local Troposphere on GPS Measurements

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It is demonstrated that no global model of the wet tropospheric zenith delay is able to reproduce with comparable accuracy the value obtained directly on the basis of aerological sounding. The spectacular artifact resulting from the global model application are apparent seasonal variations of the GPS station altitude with respect to the reference ellipsoid. The method for the construction of a local wet tropospheric zenith delay model is proposed, based on a sufficiently representative sample of local aerological data. Its systematic error does not exceed that of instantaneous local wet tropospheric zenith delay determination from aerological data (0.5 cm) and reduces the apparent seasonal variations of altitude. The model is very convenient in every day use: it is sufficient to multiply the value of actual refractivity at the ground level by a certain factor determined for a given month.

OP.X.3: Small Perturbations on the Galilean Satellites

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Today we have a precision of about ten kilometers in the observations of the galilean system. Moreover, the galileo spacecraft offers the opportunity to improve in a very strenghtening way the modelisation of this system. Hence, it may be interesting to study the influence of small perturbations which are still neglected, like the satellites'oblateness or inertial forces link with the oblateness of the central body. We used a numerical method to test the effect of such perturbations. It appears that most of the perturbations tested look more influant than what we expected, maybe because of the strong masses, volumes and J_2 coefficents of the galilean satellites. Here are reporting the main results we obtained.

OP.XI.2: Lyapunov Stability for Lagrange Equilibria of Orbiting Dust

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We examine the basic dynamics associated with a simple model of a dust particle interacting with a planetary gravitational field and solar radiation pressure. No attempt is made to model a particular planetary ring because our goal is to uncover generic properties of the model. Thus a number of important details are omitted, including; plasma fluctuations, particle-particle collisions, time dependent variations in the magnetosphere, etc. This model matches with that of a Rydberg atom in combined magnetic and circularly polarized microwave fields and we find the presence of global equilibrium points that are analogous to the Lagrangian equilibria of the circular restricted three-body problem. The dynamics around these points proves to be of special interest, so that the stability of them is an important question.

We perform linear stability analysis of the equilibrium points in order to establish stability conditions in terms of the two free parameters of the problem. However, linear stability does not ensures Lyapunov stability and further analysis is needed. To go further in the analysis, we apply a theorem due to Arnold that ensures Lyapunov stability almost for every pair of the free parameters but for some resonant cases. These resonant cases are analyzed by studying the phase flow on the reduced phase space after normalization. We use extended Lissajous variables and Morse theory.

OP.II.2: Chaotic Celestial Pachinko

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Poincare first discovered chaos through the homoclinic/heteroclnic tangle in the 3-body problem. NASA/JPLs Genesis Mission to collect solar wind samples near L1 uses the heteroclinic behavior between L1 and L2 for the design of its low-energy Earth-return trajectory (6 m/s total deterministic delta-v for the entire mission after launch in 2001). Work on this trajectory led us to the computation of heteroclinic cycles between periodic orbits around L1 and L2. The chain of homoclinic and heteroclinic cycles provide a system of dynamical channels guiding the motions of minor bodies from the Zodiacal dust to objects beyond the Kuiper Belt. In particular, this provides a mathematically rigorous dynamical explanation using symbolic dynamics for the phenomenon of the Temporary Capture of Jupiter comets. See Ross' presentation at this conference for details. Furthermore, the dynamical channels of each of the Sun-Planet and Planet-Satellite pair provide a network of dynamical tunnels spanning the entire Solar System. The transport of dust, asteroids, comets and Kuiper Belt objects are all affected by these ancient and hither-to-unknown passage ways in the Solar System. This transport mechanism is closely tied to the mean-motion resonance structures thereby determining in part the morphology of the Solar System from that of the Zodiacal Dust Tori to the various ring and belt structures within the Solar System. Many interesting applications of this theory to new space mission concepts are possible such the "Petit Grand Tour" of Jovian satellites and low-energy lunar missions with ballistic captures. See Koon's presentation for details. This is joint work with W.S. Koon, J.E. Marsden, and S.D. Ross.

OP.XIV.2: Dynamical Method for the Analysis of the Systematic Errors in Stellar Catalogs

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The recent introduction of the new reference frame and the new star catalogues Tycho, Hipparcos, G.S.C., etc. give special interest to the study of the possible existence of systematic errors among them and between each catalogue and the reference frame.

This last process may be approached by several methods like the analysis of the residuals given by the O-C (Observation minus Calculus) errors of the minor planets. These errors are partly due to the reference and partly to an inaccurate determination of the initial constants.

In this paper a method to approximate the residual function is developed. This method is exact till second order (included) and it allows to develop more precise equations to determinate the signal and the initial constants.

OP.I.5: Rigid Bodies Problems in Celestial Mechanics

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The aim is to present variety of problems connected with the study of dynamics of rigid bodies in celestial mechanics. Different topics are discussed: mathematical structure of problems involving rigid bodies, symmetries, regular solutions, approximations, question of integrability of selected models. As illustration the novel presentation of the unrestricted model of a symmetric rigid body and sphere is given and new classes of particular regular motions are shown. The solution of the problem of integrability of equation of motion of a rigid satellite in a circular problem is also presented.

OP.XIV.3: Planetary System around Pulsar PSR 1257+12 - an Overview

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Planetary system of pulsar PSR 1257+12 discovered by Wolszczan and Frail in 1992 consisting with three planets is the first planetary system around a star different then the Sun and the only known system around a neutron star. We present an overview of our works confirming its existence and we present our absolute determination of planetary masses and inclinations of planetary orbits in this system.

PP.29: Analysis of Catalog Corrections with Respect to the Hipparcos Reference Frame

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An study of different analytical procedures to compare catalogues in spherical domains is presented in order to obtain analytical expressions for the necessary reductions. In particular, we consider the case of catalogues with bounded declination limits, near which the errors must be carefully modelated. Finally, numerical results are done with respect for different catalogues with respect to the Hipparcos Reference Frame.

OP.VII.6: Determination of Masses of Six Asteroids from Close Asteroid-asteroid Encounters

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New masses of six asteroids: (10) Hygiea, (52) Europa, (511) Davida, (704) Interamnia, (15) Eunomia and (6) Hebe, were determined. The masses were calculated by means of the least-squares method as weighted means of the values found separately from the perturbations on several single asteroids. As a result of the extensive search for large asteroidal perturbations exerted by over two hundred most massive asteroids on 4500 numbered minor planets, the encounters suitable for mass determination were selected. Most of them were never used before for this purpose. The masses of Hygiea, Europa, Interamnia, Davida, Eunomia, and Hebe were determined from perturbations on respectively 8, 4, 3, 3, 3, and 2 asteroids. The masses of Europa, Davida and Hebe were calculated for the first time. Special attention was paid to the selection of the observations of the asteroids. For this purpose, a criterion based on the requirement that the post-selection distribution of the $(O - C)$ residuals should be Gaussian was implemented. As an outcome of the search for possible perturbers among 799 brightest asteroids, for all asteroids under consideration, correct dynamical models, including important perturbers, were proposed. The masses presented in this paper were obtained within the ongoing Asteroid Mass Determination Program, started in 1998 in the Wrocław University Observatory, Poland. So far, the program gave reliable mass estimates for the three largest asteroids: (1) Ceres, (2) Pallas and (4) Vesta (Michalak 2000).

OP.IV.5: Semi-analytical Method to Study Geooptential Perturbations Considering High Eccentric Resonant Orbits

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A dynamic system describing the orbital motion of artificial satellites with mean motion commensurable with the rotation of the Earth, including harmonics of high degree and order in the geopotential perturbations, is studied. The equations of motion and the geopotential are expressed in terms of convenient modified Delaunay variables. Hansen's coefficients are used and the dynamic system doesn't contain restriction for any eccentricity $0 \leq e < 1$. An integrable kernel is searched through canonical transformations. One resonant angle is fixed and the dynamic system can be reduced to a two degree of freedom system. Thanks to the properties of the Hansen's coefficients, all the coefficients of the reduced Hamiltonian are computed analytically. For low eccentric orbits analytical solutions can be obtained and expressed in terms of elliptic functions. Numeric simulations for highly eccentric orbits and 2:1 resonance are presented. The behavior of the dynamical system near the resonance is shown. Phase planes, variation of orbital elements with the resonant angle, time variation of the semi-major axis and time variation of the resonant angle are exhibited.

OP.VIII.1: Origin, Evolution and Unbiased Distribution of Near Earth Asteroids

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Due to chaotic resonant phenomena, many main belt asteroids increase their orbital eccentricity and start to cross the orbits of the terrestrial planets. When their perihelion distance becomes smaller than 1.3 A.U. they are called Near Earth Asteroids (NEAs). Understanding the dynamics of these resonant transport routes has been a brilliant result of analytic and semi–analytic Celestial Mechanics. Nowadays, fast computers and integration algorithms allow to simulate the chaotic evolution of thousands of test particles, thus quantifying from a statistical viewpoint the possible behaviors of the asteroids that escape from the main belt and become NEAs. Using this modern statistical approach, it has been recently possible to construct a model of the unbiased orbital and size distribution of the NEAs, calibrated on Spacewatch discoveries (Bottke et al., 2000). This model allows to estimate the total number of NEAs of a given magnitude, the relative repartition of the NEAs in Aten, Apollo, and Amor populations, the impact rates on the terrestrial planets and the relative importance of the major transport routes.

OP.VIII.5: Collision Probability for Earth-crossing Asteroids

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We introduce techniques to compute the collision probability for Earth-crossing asteroids in the case of short observational arcs and/or small numbers of astrometric observations. The techniques are based on initial statistical ranging of complicated Bayesian a posteriori probability densities of orbital elements. Before collision analysis, with the help of the ranging technique, we assess the systematic errors in the astrometric observations: computing a large number of Monte Carlo sample orbits allows a self-consistent estimation of both systematic and random observational errors. The techniques are applied to the lost asteroid 1998 OX_4 with non-vanishing collision probability in 2038, 2044, and 2046. In particular, we study the effects of systematic errors on the orbit determination, ephemeris prediction, and collision probability computation. Finally, we review recent overall progress in the computation of collision probabilities.

OP.XIV.1: Stellar Motions in Galactic Satellites

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The study of the motions of the stars that belong to a galactic satellite (i.e., a globular cluster or a dwarf galaxy orbiting a larger one) has some similarities, as well as significant differences, with the restricted three-body problem of celestial mechanics. The high percentage of chaotic orbits present in some models is of particular interest because it rises, on the one hand, the question of its origin and, on the other hand, the question of whether an equilibrium stellar system can be built when the bulk of the stellar motions are chaotic.

OP.IV.1: Monitoring of Variations of the Upper Atmosphere Density

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The concept of development of the system for monitoring of upper atmosphere density variations is considered. The system is based on using the satellites atmospheric drag data obtained during operation of Space Surveillance Systems. For determination of atmospheric density variations it is offered to use the orbital data estimates of low altitude satellites, whose number reaches some hundreds. The orbital elements of these satellites are updated some times per day in real time mode. So, this allows to perform operating estimation of atmosphere density variations without essential additional costs.

The concept is considered and the methodical problems of information processing for estimating the atmosphere density variations are stated. The recommendations and proposals on their implementation are presented. They are based on the results of algorithm improvement on the basis of simulated and actual information. The scientific, technological and organizational issues to require solution are considered.

The implementation of the system for monitoring of the upper atmosphere density variations would allow to increase the prediction accuracy of LEO satellites motion and to obtain the regular real data for perfecting existing upper atmosphere models.

OP.IV.4: Semi-analytical Models of Satellites Motion for Russian Space Surveillance System

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Three types of integration methods of equations for celestial body motion are known. They are numerical, analytical and semi-analytical methods. The techniques of first two types are widely applied during long time. The methods of last type have attracted attention of the experts after the launch of the Sputnik 1 satellite. The authors suppose that this development was caused mainly by requirements of space surveillance systems (SSS).

The stages of development of the semi-analytical satellites motion model for Russian SSS are considered. This development was caused by a lot of circumstances connected with the computer resources improvement, with the measurements accuracy growth and increasing of their quantity, with the more accurate modeling of perturbing factors (geopotential, atmosphere), with the growth of number of catalogued satellites. The essential influence of perturbing factors of a different nature makes impossible the obtaining of the analytical solution of acceptable accuracy. The averaging method developed by the Russian scientists was used as the methodical foundation for the development of considered semi-analytical algorithms.

The Summation of perturbations of each revolution technique was applied at the first stage (beginning of 1960). This is a first order method of finite differences.

At the second stage (1970-1980) the osculating elements at ascending node were used as the averaged ones. The perturbations of the first and second order were taken into account.

The transition to classical averaged orbital elements was hereinafter executed. Thus the number of the taken into account perturbing factors was increased essentially.

The entity of each of the considered methods and their characteristics are given.

PP.30: LEO Technogeneous Contaminants Evolution Modeling Taking into Account Satellite's Collisions

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The goal of the paper is to develop the techniques for mathematical modeling of long term orbital debris evolution within the frames of continua approach. Under the approach the evolution equations contain a number of source terms responsible for the variations of quantities of different fractions of orbital debris population due to fragmentations and collisions. The efforts were concentrated on determining the source terms for the evolution equations, developing the numerical-analitical technique for integration the evolution equations making it possible to obtain results within a reasonable time interval using modern PCs. The suggested method for orbital debris evolution modeling has the following peculiarities:

- making use of a statistical approach describing the current debris environment in the form of distribution functions for the main elements of debris orbits;
- applying the averaged description for the sources of space debris production;
- taking into account collisions of debris fragments of different sizes (including non-catalogued ones) that could lead not only to debris self-production but also to a self-cleaning of the Low Earth Orbits;
- developing semi-analytical numerical methods for integration of the governing system of evolution equations in partial derivatives.

Examples of long-term forecasts of the space debris environment are discussed. The role of collisions of debris fragments of different sizes in the overall processes of space contamination and self-cleaning of the low orbits is evaluated.

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PP.31: The Photographically Observed Meteors of (Pegasids?) Stream Associated with Comet 18P/Perrine-Mrkos

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Studying the dynamics of individual particles of a modeled meteor stream associated with comet 18P/Perrine-Mrkos on the basis of gravitational action exclusively, it is possible to reveal an actually existing, low numbered, diffuse stream of this comet. The meteors of the stream can be distinguished comparing, in appropriate moments, the orbits of modeled particles with the orbits of photographically observed meteors, which are contained in the catalogue of the IAU Meteor Data Center in Lund. The characteristics of found stream is similar to that of the Pegasids stream, but the undoubted identification of both streams is still questionable. A transparent difference is in the position of mean radiant of found stream, which is situated not in Pegasus, but in constellation Cygnus, near star τ Cyg.

OP.VI.1: A New Vision of the Mean Motion Resonances in the Solar System

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The interest in the mean motion resonances (MMRs) is historically related to the existence of macroscopic (Kirkwood) gaps in the asteroid belt, to the almost resonant orbits of pairs of giant planets, which made difficult an analytic computation of their ephemerides, and to the Laplace resonance among the Galilean satellites of Jupiter. While for the 3:1 and 5:2 Jovian MMRs, it was understood that the secular dynamics driven by solely Jupiter opens gaps in few Myr, the clearing of the 2:1 resonance requires 0.1–1 Gyr and a different dynamical mechanism. As the orbital motions of two planets and of the asteroid are involved in this mechanism, the resonances giving rise to the instability were named the *three-body MMRs*. It was further shown why the quasi-resonant structure of the outer planets orbits favour a basically regular dynamics of both the 3:2 MMR with Jupiter in the asteroid belt and the 2:3 MMR with Neptune in the Kuiper belt. One of the most interesting recent findings was however that the three–body resonances are dense in the small–body belts causing strong chaos of orbits of many real objects (40% in asteroid belt have LCE > 10^{-5}yr^{-1}) and slow chaotic evolution of their eccentricities. The three–body resonances are different from the Laplace resonance of the Galilean satellites as they do not necessary involve two coupled two–body MMRs as in the case of Europa which is in the 1:2 resonance with Io and in the 2:1 resonance with Ganymede.

OP.V.1: Coordinated Orbital Control for Satellite Constellations and Formations

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Satellite constellations and formations pose strict requirements to the orbital control design. Relative positioning among the satellites, with quite limited tolerances, is instrumental to satisfy mission goals. The amount of data to be considered to compute a control action is quite high, as the system state vector has to include all platforms belonging to the constellation. An autonomous, on board control capability is the correct target in order to reduce downlink requirements and ground segment tasks. Therefore, computation tasks has to be limited to a reasonable level in terms of time and memory allocation. Due to the autonomy, robustness is mandatory.
Previous experiences at the Universita' di Roma indicated several possible solutions. This paper aims to cover the most interesting of these approaches, directly related to the work performed in the 90s by Colin McInnes. His introduction in the orbital control field of a classical dynamical system tool, as the Lyapunov method, should be helpful to identify convenient strategies.
This method is here applied to a numerical model in which all satellites are linked by a virtual spring network. Orbital perturbations acting on the constellation/formation move the satellites from the desired configuration. The distance between the current, perturbed orbital distribution of the platforms and the desired one is represented by means of the elongation of the virtual spring. Stretching of the springs define the amount of the control action to be performed, and, as support points for virtual springs are not fixed but connected to the satellites, distribute this action among all the platforms.
The results presented are mainly focussed on the convergence of the state vector to the desired configuration and on the amount of control action (i.e. on the propellant consumption) needed.

OP.XII.3: Near-Earth Asteroids Orbits Improvement Using Singular Values

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Some results of the singular value analysis of the problem of estimation of initial orbital parameters of NEAs crossing the Earth's sphere of influence during from 1950 to 2050 are presented. Most of these objects are unnumbered and have been observed at a single apparition.The problem of the orbits improvement of objects of such kind is ill-conditioned as a rule. Conditionality of the problem is depends principally on the length of period of observations and their distribution on the orbit, but it depends on other factors: choice of the initial epoch and numerical algorithm of solution. The numerical experiments demonstrated that condition number can be considerably decreased by means of corresponding choice of the initial epoch. In order to not to make worse conditionality of the problem by calculations algorithms based on the orthogonal transformations and stable with respect to errors of the input data are used in improving the initial orbital parameters. The singular value analysis of the equations of conditions has been carried out and a vicinity of the matrix A of the differential coefficients to the singular one has been evaluated for every object. Methods of the stabilization of the solution have been applied for ill-conditioned matrices. The stabilization is carried out by means of the singular value decomposition of the matrix A and by using additional equations on the basis of the first derivatives of the observed coordinates. The estimation of the accuracy of solution of minimal norm of ill-conditioned problem on the example of different samples of observations of NEAs Hathor and Toutatis is given.

PP.32: Development of the Numerical Theory of the Rigid Earth Rotation.

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Development of the numerical theory of the rigid Earth's rotation is carried out in the Rodrigues-Hamilton parameters, which define a position of the principle axes of inertia of the Earth with respect to the fixed ecliptic plane and equinox J2000.0. The rigid Earth rotation is a result of the gravitational interaction of the Earth's body with the point mass disturbing bodies (the Sun, Moon and major planets). The geocentric motions of the disturbing bodies are provided by the ephemeris DE403/LE403. The numerical integration of the rotational motion equations of the rigid Earth is carried out over a 600 yr time interval. The results of the numerical solution of the problem are compared with the semi-analytical solution of the Earth's rotation SMART97 (Bretagnon et al., 1998). The dependence of the results of the numerical integration on the errors of DE403/LE403 ephemeris is investigated.

OP.XI.4: Frequency Map and Global Dynamics in the Solar System : Short Period Dynamics of Massless Particles

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Frequency Map Analysis (FMA) is a refined numerical method based on Fourier techniques which provide a clear representation of the global dynamics of multi-dimensional systems, which is very effective for systems of 3 degrees of freedom and more, and was applied to a large class of dynamical systems (Solar System, galaxies, particle accelerators,...). FMA requires only a very short integration time to obtain a measure of the diffusion of the trajectories, and allows to identify easily the location of the main resonances. We have performed a complete analysis of massless particles in the Solar System, from Mercury (0.38 AU) to the outer parts of the Kuiper belt (90 AU), for all values of the eccentricities, and several values for the inclinations. This provides a complete dynamical map of the Solar System, which is, in this first step, restricted to mean motion resonances. The precise extend of the resonant islands in the phase space has been determined, and the vicinity of the phase space has been plotted for the 62 best known Kuiper belt objects. We have thus set up a system for the analysis of the numerous planetary systems which are expected to be discovered in the near future. As an example, we present the application of this method to the understanding of the dynamics of the newly discovered υ-Andromedae system.

OP.VIII.4: The Reconstruction of Genetic Relations between Minor Planets, Based on their Orbital Characteristics

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The method of fast determination of minimal distances between orbits (d) is developed. It is proved, that value of d and coordinates of area, where it reached, are important criteria at search genetic related orbits. In results, the very anisotropy distribution of points of intersections of Near-Earth asteroids (NEA) orbits is obtained. The remarkable concentration of intersection points exist near heliocentric longitudes l=320-360 degrees. In according of cluster analysis by longitude and heliocentric variables, 3 independent compact groups of intersected orbits may be selected in this direction. Moreover, similar but not so large groups of orbit meet at another values of l. The complex of programs for study possible collision history of minor planets is developed. The electronic databank is created. Our bases may updated daily in agreement with following schema. It give us ability to fastly take into account all changes in near Earth space and in main belt. For more suitable using, calculation divided into few groups: Near Earth Asteroids (NEA), Trojan (trn), Marscrossers (mrc). For each groups every day may be calculated: - contents (include objects with poor determined orbits), - mutual minimal distance between orbits, - triplex (or multiple) intersections points position - this result followed by picture. User can change criteria of semicrossing, or agree with our. - rate of change minimal distance between orbits by perturbations of elements. Any theory of perturbation can be insert in this equations. - statistical marks - possibility, distribution and other. - for more complete description of possible catastrophic collisions places, calculation of minimal distances asteroid with fireballs is developed. The meteorites are considered particularly. - the determination of minimal distances orbit of each studied object with main belt (numbered) planets is make. It give us ability to classify minor planets by it's most possible origin.

PP.33: On the Behaviour of Stationary Point in Quasi-central Configuration Dynamics

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The system of N massive points m and central mass M, formed central configuration is considered. The equation of motion for testing particle has written in different coordinate system. The comparison of different form of equation of motion in problem is developed. For large N, the equations, correct both for odd and even number of particles are given. It is shown, that the libration points in considered system may be determined from algebraic equation of 5-th degree. The comparison of different ways of solution this equation is given. Main attention is given case of large N. It is obtained, that at large mass of particles outside libration point disappear. For inner libration points the limit distance l exist - libration points cannot be close then l to the central mass M at fixed N and arbitrary m / M ratio. In case small m / M solution for libration points in problem have as a limit similar solution for 3-body collinear points. Then we consider quazi-central configuration - chain of particles at elliptic orbit and obtain stationary distribution of particles in this case. We estimate the rate of eccentricity change under mutual gravitation interaction of ring' s particles. The result is compared with numerical calculations. The inclined ring may be considered by similar way. The modeling of ring, consist of 250 particles is developed by simple Euler scheme (leapfrog integrator). In result, the number of collisions in dependence of particles mass and number and initial conditions is estimated. As a most really application of such system, we may note a planetary rings, where described associations stabilizing all construction, rotating as a solid body.

OP.II.1: Resonance and Capture of Jupiter Comets

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A number of Jupiter comets such as *Oterma* and *Gehrels 3* make a rapid transition from heliocentric orbits outside the orbit of Jupiter to heliocentric orbits inside the orbit of Jupiter and vice versa. During this transition, the comet is frequently captured temporarily by Jupiter for one to several orbits around Jupiter. The interior heliocentric orbit is typically close to the 3:2 resonance (three revolutions around the Sun in two Jupiter periods) while the exterior heliocentric orbit is near the 2:3 resonance (two revolutions around the Sun in three Jupiter periods).

An important feature of the dynamics of these comets is that during the transition, the orbit passes close to the libration points L_1 and L_2. The points L_1 and L_2 are two of the five equilibrium points for the restricted three-body problem for the Sun-Jupiter system. Amongst the equilibrium points, L_1 and L_2 are the ones closest to Jupiter, lying on either side of Jupiter along the Sun-Jupiter line.

We conclude that studying the libration point invariant manifold structures for L_1 and L_2 is a starting point for understanding the capture and resonance transition of these comets. The recently discovered heteroclinic connection between pairs of unstable periodic orbits (one around the L_1 and the other around L_2) has significant implications for the aforementioned resonance transition and temporary capture of Jupiter comets.

The stable and unstable invariant manifold "tubes" associated to libration point periodic orbits, of which the heteroclinic connections are a part, act as conduits in the phase space transporting material to and from Jupiter and between the interior and exterior of a Jupiter's orbit. Temporary capture and collision orbits such as comet *Shoemaker-Levy 9*'s can be modeled via these dynamical channels. This is joint work with W. Koon, M. Lo, and J. Marsden.

OP.III.4: Determination of Orbit of Geosynchronous Space Debris Kupon Satellite Using its CCD Observations at 2-meter Telescope at Terskol Peak

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The CCD and photometric observations of geostationary Kupon (97070A) satellite were performed using the astronomical complex of the two-meter telescope located at the Terskol peak in the Northern Caucasus at 3127 m altitude. The observations were performed at the different stages of the satellite operation, namely, at the launch and transition orbits (since November 12, 1997 till December 3, 1997), at the controlled orbit (since January 17, 1998 till March 17, 1998) and at the libration orbit (since April 18, 1998 till February 14, 2000). The satellite became a space debris object after an on-board failure took place on March 18, 1998. The small size of the CCD camera field required using the Guide Star Catalogue in astrometric processing of star and satellite coordinates. The root-mean square (rms) errors of the satellite spherical coordinates are 0.5-1.0". The satellite orbit was derived using all the collected observations. The rms errors of the satellite coordinates are 50-200 m at 2-100 day orbital arcs without orbit corrections. The regular monitoring of Kupon allowed us to detect another geosynchronous satellite Arabsat 1C (92010B) on January 18, 1998 at 4-5' distance from Kupon. Arabsat 1C was moved from 31° E to 55° E about 1-2 days before our "discovery". The regular CCD observations and orbit determination of both satellites allowed us to predict and observe five close encounters of Kupon and Arabsat 1C at 1.3-4.2 km happened in February - March, 1998. Such close encounters are dangerous for communication satellites since they can lead to their collision. Using the observations of Kupon obtained on April 18 - July 28, 1998 we derived that the satellite would librate between 55.0° and 94.8° E with the libration period equal to 769 days. On April 24, 2000 Kupon will return to the longitude 55.0° E from which it escaped. The most of the results presented in the paper were derived almost in the real time, i.e. one to three days after the observations were performed.

OP.X.4: An Analytical Theory of Motion of Nereid

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In this paper, an analytical theory of motion of the second Neptunian satellite Nereid is constructed using Lie transformation approach. The main perturbing forces which come from the solar influence are only taken into account. The disturbing function is developed in powers of the ratio of the semimajor axes of the satellite and the Sun and put in a closed form with respect to the eccentricity. The theory includes secular perturbations up to the fourth order, short, intermediate and long period perturbations up to the third order. The osculating orbital elements which describe the orbital motion of Nereid are evaluated analytically. The comparison with the numerical integration of the equations of motion gives an accuracy on the level of 0.3 km for the semimajor axis and 10^{-8} for the eccentricity over a period of several hundred years.

PP.34: A Mapping Model for the Coorbital Problem

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We derive a symplectic mapping model for the coorbital restricted problem of three bodies using a method based on the averaged Hamiltonian. This mapping is a useful tool to investigate the chaotic structure of the phase space and, in particular, to obtain the location of the stability boundaries in the coorbital problem.

OP.II.4: Coupling of Translational and Rotational Motion Through Mutual Gravitation of Two Bodies

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The effect of mutual gravitational interactions between two bodies is investigated. During such interactions the rotational and translational motion of both bodies will become coupled, leading to shifts in their initial rotational and orbital states. We focus specifically on interactions that occur when the relative orbit between the bodies is eccentric. For this case, large changes to the relative orbit and rotation states can occur around each periapsis passage. We develop analytical estimates of the interchange between orbital and rotational angular momentum and energy that occur during each interaction. The main results are derived for the interaction of a dipole with a sphere. Extensions of the theory to interactions between two dipoles are also considered. Specific applications of the result can be made to a variety of situations, including the interactions of asteroids and comets with small ejecta, co-orbitals, or planets, and the interactions of a spacecraft with an asteroid, comet, or planet. The results of the analysis are verified with numerical integrations of interacting bodies. The numerical integrations model one of the bodies as a general mass distribution and the other as a series of connected point masses.

PP.35: Inclination Change Using Atmospheric Drag

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The current space exploration capacity is very limited by the excessive amount of fuel necessary to deliver and to transport loads in space. That situation motivated the development of techniques for the accomplishment of orbital maneuvers using natural forces, substituting, at least partly, the propulsive forces, as the atmospheric maneuvers do. Several control methods of vehicles crossing the atmosphere have being studied to assure the maintenance of the acceleration and of the heating of those vehicles inside limits previously defined. According to Miele (1996), the fuel economy for an atmospheric planar or quasi-planar transfer between an geostationary orbit and a low orbit, for example, can reaches 60% of the fuel that would be worn- out on a equivalent Hohmann transfer. In this scenery, the present work proposes the analysis of atmospheric missions through the development of a software for maneuvers calculation with continuous thrust to a vehicle that comes to use the terrestrial atmosphere to accomplish orbital changes. Several simulations were accomplished with the objective of obtaining the inclination variation due to the vehicle passage by the atmosphere. The maneuvers with plan change were chosen for this study, for they be highly costly in comparison to other orbital maneuvers and so they could generate good examples of atmospheric maneuvers application. The comparisons were made among maneuvers totally propulsive accomplished with continuous jets and maneuvers partly propulsive and partly atmospheric. However, the several simulations showed that this problem is highly dependent of initial conditions such as mass of the vehicle and initial and final orbital elements. Could be shown more advantageous to accomplish a gone down until the terrestrial atmosphere into certain cases and completely disadvantageous in others.

PP.36: On Modeling of Small Celestial Body Fracture in Planet Atmospheres

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The disruption of celestial body such as meteoroids, cometary's fragments and asteroids is investigated by mathematical methods. The gas dynamic forces, inertial force and radiation act on the body. The main results of the paper are related to the creation of stress-strain and phase transition models and simulation of the celestial body fracture and breaking up during its flight in an atmosphere.

The velocity of the body and its ablation during the first stage of the flight in an atmosphere are determined on the basis of the solution of the system of equations of the physical theory of meteors. The body is assumed to have form of body of revolution during its flight, before break up.

We suppose flow is axial-symmetric and we introduce cylindrical or spherical system directed along the trajectory. The thermoelastic problem for a homogeneous isotropic body is solved by numerical and analytical methods. The quasi-static approximation is also used. Pressure distribution on the flying CB is known. The basic system of equation for thermoelastic behavior of CB material includes the Lame equation for displacement and the heat equation for temperature. The local fracture can arise inside the body as well as near its surface. During motion along the trajectory, the inner fractured domain of the body will be increased and expanded toward body's boundary. The whole body is supposed as fractured one when the domain of crushed material occupies an inner part of the body and includes segments of the body's surface, i.e. fractured zone occupies place extended from one side of the body's surface to an opposite side. It's mean that entire body is divided into two (or more) pieces of uncrushed material and the crushed volume, which is significant part of the initial body's volume. Four criteria of fracture have been used in the calculation. The developed methods were applied to simulate the flight and disrupter of icy bodies (fragments of comet heads), stone CB and metallic meteorites. Comparisons with observation data were made for real events.

OP.II.3: Stability of Planar Satellite Motions in a Circular Orbit

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Our contribution is devoted to the satellite attitude dynamics in a central gravity field. We investigate, under the linear approximation, the stability of planar motions – one-parameter family of special solutions of the equations of the satellite attitude – in the case of a circular orbit.

An important feature of the phase space structure of the system is the existence of a heteroclinic loop. It allows us to derive asymptotic formulae characterizing properties of planar motions with a period substantially larger than the orbital period. Using these formulae it is possible to reveal the alternation of stability and unstability regions while the parameter varies.

We present results of extensive numerical investigations of stability also. With the aim of classifying stability properties and to visualize the obtained information in the most clear form, different diagrams are drawn.

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PP.37: Destruction and Ablation of Meteoroids in Atmosphere of Planets

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An asymptotic model for the description of meteoroid trajectory in the atmosphere is developed. The model is applicable at large values of mass loss parameter. According to this model there are rates of motion, when whole ablation of a body is completed prior to the beginning its deceleration. The given model is applied to two actual bolides which were observed by stations of Czech part of the European Network in 1997. One of bolide moved with a constant speed along light segment of its trajectory. The asymptotic model has given values of ablation coefficients. This coefficient for second braking bolide is in a good agreement with value determined on its deceleration. The application of the asymptotic model to large meteoroids has given the formulation of the new concept the 1908 Tunguska fall. According to these representations, the evaporation of fragments of destroyed meteoroid has taken place in atmosphere at speed of motion, practically equal to speed of entry. The last phase of the Tunguska phenomenon the fall on the Earth of a shock wave and the gas driven after it explains the forest fall and burning of trees and the absence of an impact crater. Analytical models for destruction of meteoroid in atmosphere and consequent motion and ablation of a debris cloud are developed. A sequential disintegration describes motion of bodies of the mean sizes. The fragmentation of large meteoroids occurs according to model of instantaneous destruction.

The motion and ablation of a debris cloud are described with the help of classical equations of meteoric physics with a variable area of cross-section. The variability of this area reflects speed of accumulation of fragments in the cloud and its interaction with atmosphere. In all cases a trajectory of a destroyed body was calculated by means of the simple analytical formulas. A comparison with the numerical solutions shows the satisfactory consent. The analytical solutions are used for the solution of an inverse problem of meteoric physics, i.e. for determination of meteoric bodies parameters based on observational data of a light segment of its trajectory.

PP.38: On the Stability of Saturnian Trojans at High Inclinations

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Several papers have been written recently investigating the stability of Saturn's Trojans. Most of these papers treated low inclination orbits, only Zhang and Innanen (1989c) considered orbits with high inclination. However, their integration time was smaller than 100000 year, though we know from Innanen and Mikkola (1989) that the triangular Lagrangian points of Saturn become unstable after 100000 year. Thus the question is, how the orbits will evolve at high inclinations if we integrate these orbits for more than 100000 year.

I have studied the evolution of about 20000 test particles distributed near the Lagrangian points of Saturn for intervals up to 10 million year in the model of the Sun-Jupiter-Saturn-Asteroid system using a 4th order symplectic mapping method described by Wisdom and Holman (1991). The initial semimajor axis (a) of the test particle was varied from 9.08 to 9.96[AU] with a step of 0.04. I also varied the mutual inclination (i_M) between Saturn and the test particle from 0^o to 50^o with a step of 5^o and the argument of the pericenter of the test particle between 0^o and 360^o.

The unstable hole at L_4 and L_5, found by Innanen and Mikkola (1989) in the planar problem, are evident also in the spatial case. Stable orbits can exist farther from the Lagrangian points, below $i_M \leq 15^o$. For higher inclinations the orbits become unstable in 10 million year. The time for which the test particle is locked in the 1:1 orbital resonance rapidly decreases when we increase the inclination of the test particle, namely over 35^o the stability time is less than 300000 year.

PP.40: Numerical Simulation of the Motion of Small Bodies of the Solar System by the Symbolic Computation System "Mathematica".

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The problem of numerical simulation of the motion of the Solar System's small bodies with various length of computer word (in decimal digits) have been solved by the symbolic computation system "Mathematica". The problem of N bodies and the perturbed two-bodies problem have been considered.

The substantiation of various methods for estimation of accuracy of numerical integration are given. It is shown that the using of computer word with large number of decimal digits can be very useful for the studying of close approaches of small bodies with large planets.

Furthermore the problem of estimation of initial orbital parameters of small bodies' motion with computer word of large length have been considered. The using of large number of decimal digit positions can be very essential for solving ill-condition problems of calculation of the motion's parameters and acting forces. The determination of orbit of near-Earth asteroids observed at single-apparition is considered as an example of application of the developed software.

PP.39: Numerical Simulation of the Motion of Martian Satellites

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Effective algorithms of numerical simulation of the motion of Martian moons Phobos and Deimos are given. These algorithms have been constructed using Enke-form of differential equations of the motion and regularizing and stabilizing Kustaanheimo-Stiefel variables. The influences of harmonics of areopotential and the Sun and the tidal effects have been taken into account in the process of simulation, the interval of time equals the period covered by observations of the satellites. Initial conditions of the motion have been calculated and improved by Chapront-Touze analytical theory.

Final refinements of Fobos and Deimos orbits have been made using observational data covered interval of time from discovering of satellites to present moment. Furthermore authors have made attempts to estimate secular accelerations of the satellite's motion and parameters of tidal deformations of the areopotential. Results of these estimations are presented.

In addition a brief description of software which have been constructed for solving such problems as the calculation of high-precision ephemerides, the orbit's improvement, the determination of parameters of gravitational field and tidal coefficients, the investigation of the long-time evolution of satellite's orbits are given.

OP.VII.5: Analytical and Numerical Study of Long-term Dynamics for Trojan-Type Asteroids

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We aim to revisit the Trojan problem, i.e. the study of the long-term dynamical behavior of small bodies trapped in a 1/1 mean-motion commensurability with a planet of the Solar System. In the frame of the spatial and elliptic restricted three-body problem, we evolved semi-analytical expressions of the coorbital Hamiltonian and its derivatives, such a way they are non-singular whatever the values of the eccentricities and the inclinations. This new formalism is applied to locate the main secular resonances inside the coorbital regime and to investigate their dynamical effects by means of semi-numerical perturbative methods. This analysis allows us to discuss under a new light the problem of the existence of the Trojan-type objects with each planet of the Solar System.

OP.VII.3: Fokker-Planck Modeling of Asteroidal Transport

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We investigate the applicability of a kinetic description for asteroidal transport, through a single diffusion equation of the Fokker-Planck type. This approach is based on the assumption that a suitably calculated "local" diffusion coefficient can be used to describe the evolution of the asteroids' elements, mainly the eccentricity, even in places of the belt where chaotic motion is not dominant. We calculate numerically the diffusion coefficient in different parts of the outer belt (beyond the 2:1 resonance), in the framework of the 2-D elliptic restricted three-body (and four-body) problem(s). The corresponding *boundary-value problem* (assuming that Jupiter-crossing orbits are ejected from the Solar system) is solved. The escape statistics resulting from this formalism are compared to those coming from long-term numerical integration.

PP.3: Constructing of the Stellar Velocity Field Using Hipparcos Data

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It is well known that the stellar kinematics in the Solar neighborhood is more complicated than one described by the standard kinematical model.

It is highly desirably to have three components of a stellar velocity to investigate the velocity field in the solar vicinity.

Unfortunately, the Hipparcos catalogue does not contain the radial velocities and does contain only proper motions. That is why we cannot determine the individual spatial velocity of each star. Nevertheless, we propose the original method which allows to construct the full vector field of the stellar velocities.

The individual parallaxes allow to arrange the non-symmetrical in space selections of stars. The solutions of the Airy-Kowalski equations using such selections yield the components of the Solar motion with regard to a group of stars. The differences between the various values is the material to construct the velocity field. This is the basic idea of the method.

PP.45: Self-similar Structure Induced by Linear Three-body System

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The self-similar phase-structure around triple-collision orbits is found in the three-body problem with harmonic potential. Here, collision means the coincidence of particles. Although the system is linear, one aspect of the self-similarity is the same as the phase structure around the triple-collision singularity in the gravitational three-body problem. The initial-value distributions of solutions shows convergence to a triple-collision initial point both in the gravitational and in the harmonic problems.

PP.46: An Optical Scanning Search for GEO Debris

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Near-synchronous uncontrolled objects are searched for using a 35cm telescope. The geostationary orbit is scanned in order to follow a definite right ascension. In other words, a fixed point is observed in the equatorial celestial coordinates. The same procedure is repeated in another night. Orbits of detected objects are estimated only by the scanning observation. Therefore, follow-up observation is easy although these are not tracked constantly. As a result, the proper orbits of the respective objects are determined in parallel.

PP.47: Co-location of Geostationary Satellites by Imaginary Interaction

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The eccentricity-inclination separation is improved so that it does not need multiple-part maneuvers even when there are various effective cross-section to mass ratios. The relative eccentricity-vectors between the co-located geostationary satellites are controlled as if repulsive interaction with frictional force were applied to the terminal points of the vectors. Numerical experiments confirm that coincidence of eccentricity vectors is avoided by a single maneuver.

PP.41: An Efficient Algorithm for Approximate Evaluation of Hansen Coefficients

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On the basis of polynomial approximations and some special systems of recurrence formulae we develop an efficient algorithm for computation of Hansen coefficients and their derivatives in theories of motion of celestial bodies. The recurrence algorithm is constructed with the help of a special system of recurrence relations giving a connection only between Hansen coefficients included into expansion of disturbing function of satellite or planetary motion. This system of recurrence relations is obtained by means of computer algebra and gives a possibility to make recurrences both from low to high and from high to low harmonics of disturbing function for perturbations both from external and internal bodies. Computation of initial values for recurrences and correction of values of Hansen coefficients inside the recurrences are made with the help of approximation of Hansen coefficients by polynomials with respect to eccentricity. We investigate in detail the numerical efficiency and some other properties of different approximating schemes: in particular, Lagrange interpolation, Taylor expansion and Chebyshev approximation. Some estimations on the accuracy of these approximations are presented in the report at the conference. Using polynomial approximations we correct the numerical values of Hansen coefficients in the recurrence process, that allows to decrease the accumulation of errors of recurrences in computing the Hansen coefficients. The author thanks DFG (Deutsche Forschungsgemeinschaft) for the financial support of this research.

OP.VII.4: Influence of Joint Perturbations from Jupiter and Saturn on the Chaotical Behaviour of Orbits of Minor Planets

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The aim of our research is to study the influence of joint perturbations from Jupiter and Saturn on the evolution of orbits of minor planets and on the formation of chaotical domains in the main asteroid belt. For solving this problem we integrate numerically the equations of motion of several thousands of real and fictitious minor planets injected into some three–body resonances "Asteroid–Jupiter–Saturn" over several millions years with the simultaneous computation of Lyapunov–Exponent. For determination of influence of joint Jovian–Saturnian perturbations on the value of Lyapunov–Exponent we consider the cases with two disturbing bodies (Jupiter and Saturn) and one disturbing body (Jupiter or Saturn), that gives a possibility to analyze, under what conditions the joint perturbations from Jupiter and Saturn (in particular, mixed-resonant perturbations) can be responsible for large values of Lyapunov–Exponent and, as a result, for the origin of chaos in motion of minor planets. We study also the dependence of Lyapunov–Exponent on the eccentricity and inclination of asteroid orbit in domains of mixed resonances "Asteroid–Jupiter–Saturn" and dependence of order of three–body resonance on semi–major axis, at which the corresponding mixed–resonance can be responsible for the chaotical behaviour of asteroid orbits. On the basis of our numerical experiments we are able to make some preliminary conclusions, in what cases the mixed–resonant perturbations can lead to formation of chaotical domains in the asteroid belt. These cases should be investigated more in detail in the future with the help of semianalytical approach. The author thanks DFG (Deutsche Forschungsgemeinschaft) for the financial support of this research.

OP.IX.2: Meteor Stream Identification with Geocentric Variables

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We show that it is possible to use geocentric variables to identify meteoroid streams. The variables we propose exhibit some important advantages over the conventional orbital elements q, e, i, ω and Ω used for many decades for the same purpose in the orbital similarity criterion introduced in 1963 by Southworth and Hawkins: *(i)* they are four, and are directly linked to the four independently measured quantities – the geocentric velocity, the two angular coordinates of the radiant, and the time of the meteor fall – while the five orbital elements are not all independent of each other; *(ii)* two of these four variables are, under appropriate conditions, near-invariant with respect to the main secular perturbations affecting meteoroid orbits, the one related to the cycle of ω.

When applied to a sample of high quality photographic meteor orbits, geocentric variables allow to reproduce the results obtained using Southworth's criterion, but not always: a few loose streams are not recognized, while many new ones are identified; moreover, in many cases the geocentric variables allow to assign more meteoroids to certain streams identified by both criteria.

OP.X.1: Evolution of the Orbits of Distant Satellites of Uranus

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The first report on the discovery of two new Uranus satellites appeared in the late October 1997. They were found by Gladman, Nicolson, Burns, Kavelaars, Marsden, Williams, and Offutt and were preliminary designated as S/1997 U1 and S/1997 U2. At present, these new satellites are given the names Caliban and Sycorax. We took the more accurately determined elements of their uranocentric orbits from the work by Marsden (IAUC, 1998, nos. 6869,6870). These data are used to explore the evolution of the orbits of Caliban and Sicorax. Although the numerical values of the orbital elements are only tentative, they give us the possibility of introducing a well-defined model that can be used to establish the main features of the satellite orbits evolution. With the discovery of new satellites Uranus stopped to be considered a unique giant planet with no distant (or external) satellites. The mean distances of Caliban and Sicorax from Uranus 7.17 and 12.21 million kilometers are so large that the effect of Uranus's oblateness is several orders of magnitude weaker than the Sun's perturbation influence. Taking into account the small masses of the satellites (their radii are 40 km and 80 km, respectively) in view of the absence of close mutual approaches, we can use, as a first approximation of the perturbation theory, the satellite version of the restricted three-body problem (Uranus - the Sun - satellite). Analysis of evolution is done on the basis of the derived general solution of the double-averaged Hill problem. The extremal eccentricity and inclination values, as well as periods of circulation of pericenter arguments and ascending node longitude arguments, are determined. Full version of this work is published in: Astronomy Letters, vol. 25, no. 7, 1999, pp. 476-481.

OP.VII.7: Schwarzschield's Nonequatorial Periodic Motion about an Asteroid Modeled as a Triaxial Rotating Ellipsoid

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For the first time existence of three-dimensional periodic motion of Schwarzschield's type in the vicinity of a rotating triaxial ellipsoid was proved by Yu.V.Batrakov in 1957. A homogeneous uniformly rotating ellipsoid of near-spherical shape was considered there. Truncated harmonic expansion of its gravity field included up to the second harmonic. The current study differs from that investigation mainly by using a closed-form expression of a triaxial ellipsoid's gravity field

$$V = k^2 \pi \rho abc \int\limits_{\lambda}^{+\infty} \left(1 - \frac{x^2}{a^2+s} - \frac{y^2}{b^2+s} - \frac{z^2}{c^2+s}\right) \frac{ds}{R(s)} ,$$

where $R(s) = \sqrt{(a^2+s)(b^2+s)(c^2+s)}$.

This allows researching ellipsoids of rather elongated shape. The particle motion equations in rotating body-fixed frame are expressed through the Delaunay's canonical elements. The searched periodical non-planar solutions are of Schwarzschield's type as their period is not necessarily equal to that of an inducing unperturbed motion. The numerical technique to search for such the solutions is developed based on the Poincare's theory of periodic solutions existence conditions. The computed solutions have been improved using numerical integrating by Everhardt's method. Some tables demonstrate found symmetrical and asymmetrical solutions for some commensurabilities and ellipsoid's shapes with semi-axies 70,60,50 km; 140,60,25 km, etc. Several figures demonstrate (for certain initial values of the Delaunay's elements and ellipsoid's models and commensurabilities) how inclination of possible initial orbit which induces the periodic motion depends on its eccentricity. In particularly, it may be noticed from these figures that both the ellipsoid's shape and particle's distance from the ellipsoid (which depends on the chosen commensurability) essentially affect the initial inclination of the periodic orbit. It is pointed to some regularities found for mutual dependence of initial elements of periodic motion. Paper includes comprehensive literature on this subject.

OP.II.5: Symmetries, Reductions and Relative Equilibria for a Gyrostat in the Three-body Problem

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In memoriam of our colleague F. Mondéjar

Some papers within differential geometry frame show a new interest in the study of configurations of relative equilibria in different problems of roto-translational motion of celestial bodies. In the problem of three rigid bodies Vidiakin (1977) and Duboshine (1984) proved the existence of Euler and Lagrange configurations of equilibria when the bodies possess symmetries (for a recent review see Zhuravlev and Petrutskii (1990). In order to study the configurations of equilibria of the general problem of three rigid bodies, from a global geometrical point of view, it is natural to consider first the problem when two bodies have spherical distribution of mass; Fanny and Badoui (1998) study this problem in terms of the global variables in the unreduced problem. It is clear, as the papers of Maciejewski (1995), Mondéjar and Vigueras (1999) show, that to work in the reduced system if the problem has symmetries, produces natural simplifications in the conditions of the equilibria, and then more general results can be obtained. This is the approach we will follow to study the problem of three bodies when two are spherical and the other is a gyrostat. Using the symmetries of the translational and rotational group possessed by the system, me perform a reduction process in two steps, giving explicitly at each step the Poisson structure of the reduce system. We make global considerations about the relative equilibria of the problem and give a general classification of them. Finally, me restrict to the zero order approximation dynamics and a complete study of the relative equilibria is made. We enlarge some results obtained in Fanny and Badoui (1998). We note also that the reduction procedure presented here applies immediately to rigid body case when me take the gyrostatic momentum be zero.

OP.XII.1: Could the NEA Dynamics Reveal Existence of the Yarkovsky Effect?

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The Yarkovsky effect is a subtle non–gravitational phenomenon related to the anisotropic thermal emission of solar system objects. Its importance has been recently demonstrated for the transport of material from the main asteroid belt (both for explaining the origin of the near–Earth asteroids and some properties of meteorites) and also in relation to the aging–processes of the asteroid families. However, unlike the case of artificial satellites, the Yarkovsky effect has never been measured or detected in the motion of natural bodies in the solar system. Here, we investigate the possibility of detecting the Yarkovsky effect via the precise orbit determination of certain near–Earth asteroids. Though the current data do not clearly demonstrate the Yarkovsky effect in the motion of these bodies, we predict that the next apparition of several asteroids (in particular Golevka, Geographos and possibly Icarus) might reveal its existence. Moreover, we show that the Yarkovsky effect may play a very important role in the orbit determination of small, but still observable, bodies like 1998 KY26. If carefully followed, this body may serve as a superb probe of the Yarkovsky effect in its next close approach to the Earth in June 2024.

OP.IX.1: Meteor Stream Dynamics

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Meteors are seen as streaks of light in the upper atmosphere when they collide with the Earth. The parent comets of these meteoroids, fortunately, tend not to collide with the Earth. Hence there has been orbital changes from one to the other so as to cause a relative movement of the nodes of the meteor orbits and that of the comet, implying changes in the energy and/or angular momentum. In this review, we will discuss these changes and their causes and through this place limits on the ejection process. Other forces also come into play in the longer term, for example perturbations from the planets, and the effects of radiation[pressure and Poynting-Robertson drag. The effect of these will also be discussed with a view to understanding both the observed evolution in some meteor streams. Finally we will consider the final fate of meteor streams as contributors to the interplanetary dust complex..

PP.43: The Prediction of the Motion of the Atens, Apollos and Amors Over Long Intervals of Time

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If we take into account two starting orbits which differ only by error of calculation of any orbital element, then after some time differences in mean anomaly between these neighbours orbits growths rapidly. It denotes, that it is impossible to predict behavior of asteroids outside this time. This time I have named *time of stability.* Equations of motion of about 1000 Atens, Apollos and Amors (AAA) were integrated 300,000 years forward using RA15 Everhart method. As the starting point point the elements of the asteroids were taken from MPC until March 2000. The Osterwinter model of Solar System was used. The calculated *times of stability* for these AAA are very short (<1,000 years - 33%, <10,000 years - 89%). The behavior of averaged times of stability of AAA are almost the same as the behavior of *survival times* of Evans an Tabachnik for testing particles in this same region (*Letters to Nature, v. 399, May 1999*).

PP.44: Long Term Evolution of Disposal Orbits Beyond the Geostationary Ring

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The effect of long term gravitational influence of the Earth, Moon and Sun, together with the Sun radiation effect was studied on randomly generated population of several thousend orbits with perigee heights beyond the geostationary ring. In recent work Breiter (1998) confirmed that the perigee hight 300 km above the geostationary radius guarantees the safety of graveyard orbits on the time span of 50 years and indicated the possibility of lower storage orbits if they have small eccentricities and if their lines of apsides coincides with the Earth-Sun line. The present work studies the stability of storage orbits on several hundreds years using a risk-imposing sample identified in above mentioned paper. Numerical investigation is performed by means of the six-order symplectic integrator.

Breiter, S., 1998, *Artificial Satellites*,**33**, 25–29.

OP.XIII.4: Modeling of Space Astrometric Observations on the Microsecond Level

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The accuracy of the astrometric observations obtained by means of the space optical interferometers, orbiting the Earth is expected to be of the order of 1 microarcsecond. The processing of such extremely high precision measurements demands the using of a rigorous theoretical model developed in the framework of the General Relativity [1].

The special software for the processing of angular distance observations with microarcsecond accuracy is developed. Using this software the simulation was made for the observations of stars received by space optical interferometer located on the artificial satellite, orbiting the Earth. The satellite orbit parameters and telescope characteristics are chosen rather close to that of Hipparcos mission. Even numerical tests with a small number of simulated measurements show the possibility to obtain spherical coordinates of stars with the accuracy better than 40 microarcsecond. The applied relativistic model did not show the valuable enlargement of the accuracy of the adjusted stellar parameters. Evidently this result arises from the strong correlations between parameters of stars and small value of addition relativistic effects. The implementation of the "real life" observational program has to improve the accuracy of the stars position determination (of the order of 10 μas). At the first step of this "real life" program it is considered to put the satellite at the Sun-Earth Lagrangian point L2, located 1.5 million kilometers from the Earth in the direction away from the Sun. Secondly, it is assumed to use one of the versions of the Guide Star Catalogue as the input one. It seems the impact of the systematic errors caused by the described above additional relativistic terms will become detectable at the noise level of measurements.

REFERENCES 1. S.A. Klioner, S.M. Kopejkin, Microarcsecond astrometry in space: relativistic effects and reduction of observations., 1992, The Astron.J., 104, N2, p.897.

OP.XII.4: The Usage of Radar and Optical Observations of Near-Earth Asteroids and Main Belt Minor Planets for Astrometry (Orbit Determination, Parameters Orientations, Mass Determinations)

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Near-Earth Asteroids (NEAs) are the solar system special class objects attracting the attention of astronomical community especially several last decades.

In this paper the results of usage the all available radar and corresponding optical NEAs observations in combined solution for different aims of astrometry are discussed. All available radar observations of 30 NEAs have been accumulated with optical ones (more than 20000 combined observations, including 230 radar and about 19800 optical ones of 30 asteroids and main belt minor planets) for global solution in different problems: the parameters orientation of FK5, the motion of dynamical equinox from 1750 till 2000 in Hipparcos system and several masses of selected asteroids have been estimated. The results are in good agreement with investigations of other researchers being used another kind of observations. In the list of asteroids with radar observations are several main belt minor planets. They have rather long observational history and smaller values of observational errors. Addition this kind observations in global solution improves the final results in every problem.

The addition of new radar observations can improve both values and accuracy of parameters under consideration. Making up observations based on the new high-precision ground-based and space techniques in the Hipparcos reference frame can give at last final answer about the existence and reason of the dynamical equinox motion. The addition several radar observations of the perturbed asteroid to optical ones can reduce the uncertainty in the factor of 2-2.5 times for the mass of perturbing asteroid.

PP.42: Relativistic Effects On Sun-Synchronous Orbits Including The Influence Of Direct Solar Radiation Pressure

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A Sun-Synchronism for a moving near earth's satellite results when the initial semi-major, eccentricity, and inclination are selected such that ascending nodal precession is easterly with secular rate 0.986^0/day (the mean orbital rate of the apparent Sun). Second order (relative to Sun, Earth, and Moon oblateness) North-South gravitational forces cause slow changes in the inclination and ascending node of a sun-Synchronouse orbit. These forces can disrupt the Sun-Synchronism. In this paper we analyze the perturbations due to the solar radiation pressure with the relativistic effects as a disturbing forces on the Sun-Synchronous orbits.

OP.IX.3: On the Transfer of Comets from Near-parabolic to Short-period Orbits

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Under the framework of circular restricted three-body problem (Sun-planet-Comet), we obtain a map model following the idea of Liu and Sun (1994) but with some modifications. The map is used to study the transfer of comets from near parabolic orbits to short periodic ones. Numerical results show that, the transfer is effective On the following cases: comets in direct or retrograde orbits crossing with the planet's orbit, or comets in direct orbits non-crossing with the planet's orbit but with their perihelion distance close to the semi-major axis of planet's orbit. The dependence of transfer probability and average time on the perihelion distance of comet orbit and planet mass are expressed as some scaling laws. The commonly adopted random walk assumption about the energy change of the comets is also inspected.We find due to the difference of typical change of the comet energy per passage, the statistics on transfer of comets in orbits crossing with Jupiter's orbit is different with those in non-crossing orbits. For comets in the orbits crossing with the Jupiter orbit, the energy change is large due to close encounter, thus the diffusion approximation does not apply. New statistical laws concerning the transfer of comets in this case are revealed with our simple model.

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